151

December 7, 1971

To the Graduate Council:

I am submitting herewith a thesis written by Mohan C. Sanwal entitled "Age, Diet and Temperature Effects on Magnesium Behavior in Rats." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Animal Husbandry.

Sam L Hansard
Major Professor

We have read this thesis
and recommend its acceptance:

Robert R. Shrode

George M. Meriwether

Accepted for the Council:

Stilton A. Smith
Vice Chancellor for
Graduate Studies and Research

AGE, DIET, AND TEMPERATURE EFFECTS ON MAGNESIUM BEHAVIOR IN RATS

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

---

by

Mohan C. Sanwal

December 1971

ACKNOWLEDGMENTS

The author wishes to express his thanks and indebtedness to: Dr. Sam L. Hansard for serving as committee chairman and his inspiration, assistance and guidance throughout the graduate study; Dr. C. S. Hobbs for his encouragement and assistance; Dr. G. M. Merriman and Dr. R. R. Shrode for serving on the graduate committee and reviewing the manuscript; Mr. H. M. Crowder for his valuable technical assistance; Dr. A. W. Humphreys, Faculty Advisor, U. T. India Association, for his continued encouragement and assistance.

Appreciation is also expressed to the author's parents, Sri and Srimati Padma Datt Sanwal, for their patience and inspiration; his brothers for their patience; and finally my thanks to Dr. Jagdish C. Bhandari, for his assistance of all kinds in making this study possible.

1002415

ABSTRACT

Recent recognition of hypomagnesemia and a condition in ruminant animals called "grass tetany" has augmented investigations of factors affecting the behavior or metabolism of magnesium. In the present study an attempt was made to interrelate body magnesium with ambient temperatures, age and selected dietary factors, using 96 young and old male rats. Results indicated that rats maintained at 3°C consumed more feed than those maintained at 23°C. Serum-Protein bound iodine (PBI) values in rats receiving low iodine diet decreased in cold, and both serum magnesium and PBI levels decreased in rats on the high potassium diet, irrespective of temperature. Tissue magnesium and calcium concentration increased on addition of dietary iodine, suggesting a greater utilization of these minerals in the presence of iodine. Kidney was the principal excretory route for both magnesium and 28-magnesium. On the normal magnesium ration, addition of iodine increased excretion of magnesium and 28-magnesium in cold exposed rats. High dietary potassium also decreased absorption, retention and tissue magnesium concentration, especially in young rats. Turnover rate of radiomagnesium was higher in soft tissues and lower in bone. Concentrations of other minerals further reflected metabolic effects.

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION.	1
II.	LITERATURE REVIEW	5
	Effect of Cold on Plasma Magnesium and Plasma Volume	5
	Effects of Cold on Magnesium Behavior	7
	Effect on the Routes of Excretion	9
	Parathyroid Effect on Magnesium Metabolism. . .	10
	Effect of Cold on the Adrenals and Magnesium Concervation.	11
	Magnesium Availability and Feed Efficiency in Animals.	12
	Role of Potassium in Regulating Magnesium Metabolism.	14
	Role of Calcium in the Tetany Syndrome.	15
	Dietary Magnesium	16
	Miscellaneous Effects	16
III.	GENERAL PROCEDURE	17
IV.	RESULTS AND DISCUSSION.	21
	Treatment Effects on Feed Consumption by Rats .	21
	Differences in Rat-PBI Values	23
	Effect on Serum Magnesium, Potassium and other Electrolytes.	25
	Treatment Effect on Tissue Concentration of Magnesium.	28

CHAPTER PAGE

Treatment Effect on Calcium and Potassium Tissue Concentration. 30

Excretion of Magnesium in Young and Old Rats. . 34

Excretion of other Electrolytes 36

Blood and Tissue Concentration of Radiomagnesium. 39

Total 28-Magnesium Uptake in Blood and Organs . 42

Effect of Temperature, Age and Diet upon Tissue Concentration of Zinc and Iron 44

Treatment Effect on Copper and Manganses Concentrations in Rat-Tissues 47

Hematocrit Values 50

V. SUMMARY 51

LITERATURE CITED. 53

VITA. 62

LIST OF TABLES

TABLE		PAGE
I.	Average Mean Ration Composition of Young and Old Rats.	19
II.	Mean Daily Feed Consumption by Young and Old Rats (corrected to 100 gm Rat weight), Fed Various Rations at 3° and 23°C.	22
III.	Protein Bound Iodine Values from Rats	24
IV.	Mean Serum-Electrolytes in Young and Old Rats Fed Different Diets at Low and Room Temperatures	26
V.	Treatments Effects Upon Tissue Magnesium Concentration of Young and Old Rats	29
VI.	Treatments Effects Upon Tissue Calcium Concentration in Young and Old Rats	31
VII.	Tissue Potassium Concentration for Different Treatments of Young and Old Rats.	32
VIII.	Magnesium and Radiomagnesium Balance Data from Rats	35
IX.	Treatment Effect Upon Intake and Excretion Values of Selected Minerals in Young and Old Rats Dosed with Radiomagnesium.	37
X.	Percent Dose and Specific Activity Values of Different Organs of Rats Thirty Five Hours after Intraperitoneal Dosing with 28-Magnesium.	40

TABLE PAGE

XI. Percent 28-Magnesium Uptake of Different Organs of Young and Old Rats, Thirty Five Hours after Intraperitoneal Dosing. 43

XII. Treatment Effect on Tissue Zinc Concentration of Young and Old Rats. 45

XIII. Treatment Effect on Tissue Iron Concentration of Young and Old Rats. 46

XIV. Treatment Effect on Tissue Copper Concentration of Rats 48

XV. Treatment Effect on Tissue Manganese Concentration of Rats 49

CHAPTER I

INTRODUCTION

Metabolic diseases are widespread among farm livestock, particularly in cattle and sheep during early lactation and late pregnancy. Hypomagnesemia, also known as grass tetany or grass staggers, is one of the most serious of these metabolic diseases. Mineral metabolism is known to play a significant role in the causation of this condition. Hypomagnesemic tetany causes a great loss of livestock and livestock products in many parts of the world, especially in areas where sheep and cattle are raised extensively, or where high-yielding and quick-maturing stock are raised and fast-growing high quality pastures are available. The condition has been reported in many parts of the world, including Holland, Britain, Norway, New Zealand, Australia and South Africa (Colby and Frye, 1951).

The incidence of hypomagnesemic tetany varies greatly from year to year and in different seasons of the year (Green, 1939). In New Zealand and Australia, the condition is found to occur frequently in the late winter or early spring (Blumer et al., 1939). Possibly temperature and humidity, together with the favorable internal environment, predispose the animal to develop the signs of what is now called "hypomagnesemic tetany". Confusion and lack of clarity in conception characterize the large literature on the tetany syndromes of cattle.

The great economic loss caused by this condition in ruminant animals can be prevented or controlled by modifying the intake of various dietary constituents, and by making the environment suitable for the normal metabolism of these minerals.

Magnesium is known to be an essential element for the proper functioning of the mammalian body (Aikawa, 1963; Kruse et al., 1932; Wacker and Vallee, 1958), and it is normally found in various concentrations in practically every organ, secretion, and fluid of the body. It is now known to be required for the activity of a great many enzymes, particularly those concerned with oxydative phosphorylation. Such functions do not yet explain the signs or symptoms observed in nutritional deficiency (Wacker and Vallee, 1958). A clear relationship between magnesium and diseases of cattle and sheep has not yet been conclusively established. Asymptomatic hypomagnesemia is frequently reported, but clinical signs are usually associated with some degree of hypocalcemia (Marshak, 1959).

There is general agreement that elucidation of magnesium metabolism has been hampered for years by methodology inadequacies (Elkinton, 1957; Wacker and Vallee, 1958), and there is ample reason to question seriously the reliability of the occurrence of pure hypomagnesemic tetany. Grass tetany occurs in young ruminants raised exclusively on milk diets and in adult ruminants near the time of parturition, when

grazing in certain areas in the spring and autumn. The causative factor(s) is not well understood, although the type in calves has also been produced experimentally in young animals through inhibiting normal rumen development (Duncan et al., 1935; McAleese and Forbes, 1959; Smith, 1957).

Some authorities have postulated hypomagnesemic tetany to be a physiological dysfunction of neural or endocrine mechanisms triggered by environmental stresses (Green, 1948). The production of thyroid hormone has been shown to be increased in animals kept under cold stresses (Dempsey and Astwood, 1943). Magnesium appears to be intimately associated with responses resulting from increased thyroxine in the circulation (Sellers and You, 1950), and higher levels of thyroxine in the circulation, possibly, also increase the urinary excretion of magnesium (Szelenyi et al., 1968). Low ambient temperatures, then, could be the cause of an increase in the rate of excretion of magnesium (Hale and Mefferd, 1958). The work of several investigators in this field has suggested a need to consider the possible role of thyroid hormone in regulating magnesium levels in the body. Along with other factors, temperature possibly influences indirectly the critical levels of plasma magnesium, by acting on such endocrine organs as the thyroids. Since individual levels of thyroxine and other hormones vary considerably, this assumption may explain why only a part of the animals in a group may suffer from acute hypomagnesemic tetany.

The present study with rats was designed to investigate some of these problems, especially to study the magnesium behavior under cold stress and the effect of age and iodine level upon thyroid status as indicated by serum thyroxine levels of rats on selected rations. The purpose of this study was to obtain data to indicate the possible relationship of these factors.

CHAPTER II

LITERATURE REVIEW

The physiological role of magnesium in animal systems, and its role as an essential nutrient, has been the subject of much attention in the last two decades. The literature, however, contains many important research reports relating to the relationship of magnesium metabolism, the endocrine status of an animal, and the subsequent effect of low ambient temperature.

Effect of Cold on Plasma Magnesium and Plasma Volume

Many investigators have reported and confirmed the increased tissue magnesium concentration and increased serum magnesium under cold stress in various species of animals (Axelrod and Bass, 1956; Hegsted *et al.*, 1956; Platner, 1960; Platner and Hosko, Jr. 1953). Platner and Hosko (1953) were probably the first to report the role of magnesium during acclimatization. They also found that the increase in serum magnesium under cold stress followed a linear relationship to a drop in rectal temperature.

Hypothermia appeared to stimulate the mobilization of magnesium from depots (Platner, 1950), but the cellular levels of magnesium were rigidly maintained at the expense of the skeletal depots (Duncan, 1954). Blood and plasma volume appeared to be decreased in hypothermia (Conley and

Nickerson, 1945), but there appeared to be a discrepancy between short term and long term exposures to cold (Rodbard et al., 1950). Deb and Hart (1956), emphasizing the difference, reported an increase in blood volume relative to body weight at five weeks of age in rats placed at 30°C for two weeks, and then at 6°C for six weeks. In these trials extracellular water had a tendency to increase relative to body weight. No change was found in the hematocrit, or blood volume, of rats exposed to 3°C for 30 days (Garcia et al., 1957); however, Brown et al. (1954) suggested that a high blood volume was associated with acclimatization to cold.

It was considered that the magnesium content of the erythrocyte and the magnesium content of the serum were not interdependent (Greenberg et al., 1933). It was considered that a higher correlation exists between the intracellular level of cations and the clinical symptomology than with the serum level of cations, particularly in magnesium deficiency (Smith and Hammersten, 1959). The clinical significance of serum magnesium measurements has been uncertain at best (Barnes et al., 1957; Elkinton, 1957), because magnesium is predominantly intracellular and it can readily be conserved in the deficiency state. In this study, the regulatory mechanism of extracellular magnesium did not appear to be particularly sensitive. Others have suggested that it is more correct to think in terms of diurnal and seasonal variations rather than concentration (Pleshchitser,

1958). In this regard, the relationship of climate to serum magnesium levels in hibernating and non-hibernating species has been reported to be highly relevant (Axelrod and Bass, 1956; Platner, 1950; Platner and Hosko, 1953).

Effects of Cold on Magnesium Behavior

Evidence in the literature suggests that both environmental and hormonal factors play a major role in regulating magnesium concentrations in the body. In one experiment, the overall metabolic rate was increased during cold exposure (Sellers and You, 1950) and thyroxine levels were increased (Yousef et al., 1967). Animals' response to cold appears to be mediated by the pituitary (Tyslowitz and Artwood, 1942) and the adrenals (Sellers et al., 1951), as well as the thyroids (LeBlond and Gross, 1943). Dempsey and Astwood (1943) reported increased activity of the thyroid gland in cold. This was accompanied by increased utilization of thyroxine in rats exposed to cold (Rand et al., 1952; Randall et al., 1959). Moreover, about a 70 percent decrease in serum magnesium has been reported by injecting thyroxine into rats exposed to low temperatures, and fed a normal diet (Vitale et al., 1959; Vitale et al., 1957a), and the magnesium requirements of rats appeared to be increased after thyroxine administration. Yousef et al. (1967) confirmed that thyroid function and metabolic rate were involved in the compensation stage of acclimatization to a new environment, and they reported thyroxine ^{131}I and PBI levels to be increased significantly

at 1°C exposure. In another study (You and Sellers, 1951), with cattle, thyroid activity was found to be higher at 1°C than at 18°C; it was also higher with feeding to appetite than with controlled feeding at 1°C. Estimation of thyroxine degradation rate was also considered in this study as a good index for quantitative evaluation of thyroid function. (Vohnout et al., 1967).

Sellers and You (1950) suggested that the increase in metabolic rate of acclimatized animals was not dependent on the hyperthyroid state, but rather on the presence of the thyroid hormone in the circulation. In a study with rats, LeBlond et al. (1944) found decreased survival in thyroidectomized animals exposed to cold. The action of thyroxine could be related to its effect on the structural integrity of the mitochondria, and magnesium could, of course, somehow prevent such changes (Vitale et al., 1957b). Tapley and Cooper (1956) were unable to state clearly whether the effect of thyroxine was related to biochemical changes or to the physical integrity of the mitochondrial system. From the work of Tipton et al. (1946) tissue oxygen consumption appears to have a close connection with the thyroid hormone. They found the activity of succinoxidase and cytochrome oxidase of liver tissure to be increased in thyroid-fed rats. You and Sellers (1951) reported an increased oxygen consumption and succinoxidase activity in rats exposed to 1.5°C. for 27 to 70 days.

Thyroid hormones might, therefore, have considerable effect on magnesium metabolism. Decreased plasma magnesium concentrations in thyrotoxicosis and increased levels of plasma magnesium in thyroid insufficiency have been reported (Hanna, 1961; Jones and Fourman, 1966). Reports that serum magnesium concentration decreased in thyroxine-fed cows, which in turn increased the incidence of hypomagnesemic tetany, have appeared (Leech and Bailey, 1953; Swan and Jamieson, 1956). Maley (1957) demonstrated decreased P:O ratios in livers from thyrotoxic rats, an in vivo effect. As far as hypomagnesemia is concerned, Forbes (1965) showed that thyroxine-treated rats did not have more severe manifestations of magnesium deficiency than others. Todd (1969), in his recent review, states that it is unlikely that there is any feedback control of thyroid function by plasma magnesium level, and that the effects of thyroid hormone on magnesium metabolism in cold are probably secondary to its effect on basal metabolism.

Effect of the Routes of Excretion

It may be pointed out that knowledge of routes by which ruminants excrete magnesium and the mechanism of control of such excretion is of value in connection with the etiology of hypomagnesemia (MacDonald and Care, 1959). Jones and Fourman (1966) have suggested that the effect of thyroid hormone on the renal transport of magnesium is direct, rather than indirect on bone resorption. They found that, in relation

to intake, urinary excretion rates were high in thyrotoxicosis and low in myxedema; plasma concentrations were the reverse. Ingram and Slebodzinski (1965), working with pigs, found that the secretory activity of the thyroid gland declined with age and that it was less at 35°C than at 25°C. Induction of hypothyroidism by excess of iodine in diet, or removal of thyroids, and treatment with anti-thyroid drug has been found to elevate the output on magnesium in urine of rats, to increase serum magnesium levels, but to decrease magnesium in heart and skeletal muscle (Szelenye et al., 1968). Hale and Mefford (1958) also reported greater urinary excretion rate of plasma magnesium at low ambient temperatures.

Parathyroid Effect of Magnesium Metabolism

Heaton (1965) suggested that the parathyroids regulate plasma magnesium by mobilization of bone magnesium, and that deprivation of magnesium increased their activity. There is some evidence that magnesium deficiency in the rat is associated with an increase in parathyroid gland activity, and it has been suggested that hypomagnesemia is the stimulus for this response (Gitelman et al., 1968). Wallach et al. (1966) reported increased plasma magnesium, inorganic phosphorus and calcium in dogs with hyperparathyroidism. Parathyroidectomized animals may (Jones and Fourman, 1966; Silbert et al., 1965), or may not (Heaton and Pyrah, 1963), have low urinary magnesium, but in rats the early response to parathyroid ablation was apparently

increased urinary excretion according to the studies by Berthaux et al. (1960) and Heaton (1965). Parathyroid hormone also appears to influence magnesium absorption from the intestine, and urinary excretion rate may be influenced by the extracellular fluid level of magnesium (MacIntyre et al., 1963). The parathyroid hormone may cause marked conservation of urinary magnesium and calcium. However, hyperparathyroidism is usually associated with both hypermagnesuria alone or with hypocalcemia and often hypomagnesemia (Heaton and Pyrah, 1963; MacIntyre et al., 1961). Additional evidence of magnesium deficits in this condition has also been presented (Jones and Fourman, 1966). The parathyroid hormone has been shown to augment urinary magnesium excretion in dogs (Roberts et al., 1954) and in rats (Carroll and Pechet, 1967; Heaton 1965). MacManus et al. (1971) concluded from their experiments with rats that magnesium deficiency inhibits the action of parathyroid hormone on its target organs.

Effect of Cold on Adrenals and Magnesium Conservation

Sellers et al. (1951) reported the adrenals to be necessary for rat survival in cold; the average survival time was found to be 12 hours in rats placed at 1.5°C for 12 to 48 hours after adrenalectomy. Hypertrophy of adrenals with cold exposure was reported by Selye (1937), but this was not taken as a reliable index of adrenal hyperactivity (Heroux and Hart, 1954). A close relationship, however, appeared to exist between adrenal cortical activity and body temperature control (Egdahl et al., 1955; Holtkamp et al., 1949).

The activity of magnesium, catecholamines and ACTH has been shown to increase during cold acclimation in rats (Neubeiser, 1958; Platner, 1960; Platner and Hosko, 1953). Adrenal glands in rats reportedly increased in weight in magnesium deficiency (Edin et al., 1970); Richer et al. (1967), however, reported that magnesium deficiency did not stimulate the adrenal cortex. The fall of corticosterone level has been reported to be a sensitive index of magnesium deficiency (Richer et al., 1968; Ginn et al., 1967). These workers found that aldosterone and plasma magnesium were increased in magnesium-deficient rats. In adrenalectomized rats, serum magnesium, plasma magnesium and magnesium concentration in muscle appeared to be increased (Conway and Hingerty, 1946; Zwemer and Sullivan, 1934). Vitale et al. (1959) have suggested the hypomagnesemia seen in primary aldosteronism to be secondary to a potassium deficiency, which resulted in kidney damage and thus poor resorption of magnesium. Hypersecretion of aldosterone may adversely affect magnesium balance and plasma magnesium level (McAleese and Forbes, 1959; Scott and Dobson, 1965).

Magnesium Availability and Feed Efficiency in Animals

The age and sex incidence, stage of pregnancy or lactation, nutritional background and profound tissue alterations observed in winter tetany of beef cows have suggested an etioligical relationship to qualitative and quantative malnutrition (Marshak, 1959). Ender et al. (1957) stressed the role of undernutrition as a factor in the etiology of tetany. Green plants generally contain abundant magnesium (Pleshchitser, 1958;

Wacker and Vallee, 1958), but there is much speculation on the matter of magnesium availability. The amount of magnesium retained by cattle has not been found to be dependent upon the dietary magnesium content, Ca:P ratio or the crude fibre content (Garner, 1950). In this regard, investigators have variously incriminated dietary potassium, nitrogen, protein, manganese, sulfates, chelating agents, and a host of other "blocking substances" (Bartlett et al., 1954; Blaxter and McGill, 1956; Marshak, 1958). Herbage magnesium has been found to be lowest in April and highest in August (Stewart and Reith, 1956). Field et al. (1958) considered 0.1 percent magnesium in dry matter as marginal.

It has been shown in cattle that serum magnesium concentration does not reflect direct changes in magnesium intake when magnesium is present in excess of requirement. Hegsted et al. (1956) have reported an increased magnesium requirement and a decreased feed efficiency in a cold environment. Magnesium requirements for growth at 12.8°C were found to be from 3 to 5 times as great as for comparable growth at 23.8°C, and a 25 percent decrease in feed utilization occurred despite a 20 percent increase in food intake in the cold.

Kunkel and Pearson (1948) found 2 to 30 mg magnesium per 100 gm of diet fed to magnesium deficient rats to be adequate for blood magnesium and for growth. On assigning a value of 100 for the availability of magnesium in $MgSo_4$, as determined by blood levels, the average values for MgO, $MgCo_3$ and magnesium from young wheat plants grown in a field where grass tetany had occurred were 61, 96, and 76, respectively.

Role of Potassium in Regulating Magnesium Metabolism

Suttle and Field (1969) induced hypomagnesemic tetany in ewes and lambs by increasing potassium intake and decreasing magnesium intake. Plasma magnesium concentrations were reduced. The work of many investigators (Blaxter et al., 1960; Hendricks, 1962; Odell et al., 1952; Suttle and Field, 1967) suggest that when the potassium content of hay and concentrate diet was raised to a level found in the tetany-inducing pastures, the apparent availability of magnesium to sheep was markedly reduced; however, no hypomagnesemia was observed.

Since highly fertilized pastures have been rich in potassium and low in sodium, it seemed possible that increased aldosterone secretion might explain hypomagnesemia when it occurs in animals feeding on pastures being intensively grazed. However, it has not been possible to confirm that this is a factor of major importance in ruminants, and it appears probable that any effect on magnesium metabolism was secondary to the effect on sodium (Termouth and Beattie, 1970).

Reduction in food intake per se has lowered serum magnesium level in ruminants (Herd, 1966), and low ambient temperatures might lower the magnesium level further by increasing the potassium content of the blood and some tissues (Baker and Sellers, 1957; Booker et al, 1952). This might have been the subsequent reason for the fall in serum values observed by Kunkel et al. (1953) and Suttle and Field (1969). Both potassium and magnesium are intracellular ions, suggesting an

intimate relationship between the two cations (Eichelberger and McLean, 1942). Suttle and Field (1967) have shown the addition of potassium to the diet to cause a decrease in the urinary output of magnesium by 33 percent, and to increase significantly the levels of phosphorus, sodium and calcium by 98 percent, 76 percent, and 150 percent, respectively. Fecal output of magnesium and potassium were increased, whereas serum magnesium was decreased by 0.4 mg per 100 ml and serum potassium by 4.9 mg per 100 ml.

Role of Calcium in the Tetany Syndrome

Many studies have already indicated a constant relationship between hypocalcemia and the occurrence of tetany (Parr, 1957; Smith, 1957), whereas, hypomagnesemia without hypocalcemia was clinically silent. Such studies have reduced the validity of earlier studies wherein hypomagnesemia without hypocalcemia was shown in tetany cases (Duncan et al., 1935). Moreover, many workers have shown the common occurrence of hypomagnesemic plus hypocalcemic tetany (Leffel et al., 1958; Marshak, 1958; Randall et al., 1959; Smith, 1957; Udall, 1947). In cattle, no clinical state has been proven to be the result of hypomagnesemia alone (Elkinton, 1957; Marshak, 1958), and the occurrence of asymptomatic hypomagnesemia has been widely recognized (Allcroft, 1947; Bartlett et al., 1954). Cases of non-hypomagnesemic tetany have also been reported (Duncan et al., 1935; Jones, 1954).

Dietary Magnesium McAleese and Forbes (1961) reported the average dietary requirement of magnesium in rats, for a maximum weight gain, to be 115 ppm, a value not affected by environmental temperature or time of experiment. Dietary levels averaged 100, 116 and 130 ppm at increasing calcium levels. For maintenance of "average" blood magnesium levels, about 365 ppm were required. This value was unaffected by time or temperature, but was influenced by dietary calcium, being 285, 399 and 413 ppm at increasing calcium levels. It was also noted in their experiment that, with a basal diet having 20 ppm of magnesium, rats lost 80 percent of the magnesium originally present in their femurs while still gaining in femur calcium. McAleese and Forbes (1961) concluded that the rat can satisfy its requirement for magnesium, judged by bone magnesium concentration, at a lower concentration of dietary magnesium at 10°C than at 23°C.

Miscellaneous Effects Moodie (1968) reported posterior pituitary hormone in sheep to have no observed effect on magnesium metabolism. Thyrocalcitonin, a recently discovered hormone, although markedly affecting serum calcium levels, has not been shown to have a significant effect on serum magnesium concentration (Gudmundsson et al., 1966). This hormone has been reported to reduce the excretion of calcium and magnesium cations in thyro-parathyroidectomized rats receiving parathyroid hormone, probably because it greatly diminished the hypercalcemic response (Anast et al., 1967; Carroll and Pechet, 1967).

CHAPTER III

GENERAL PROCEDURE

Ninety-six male albino rats, comprising two age groups, were used in this experiment with two trials. Both young (twenty-eight days) and old (one to two years) rats were used in this study. Younger rats could not be used because twenty-one day-old rats died of acute cold exposure and pneumonia within hours after exposure to 3°C.

All rats were maintained at 23±1°C or 3±0.5°C. Half of the animals from each age group were exposed to these ambient temperatures for the twelve to thirteen days of the total experimental period.

Both the warm and cold-exposed rats were caged in groups of three. All animals were given de-ionized water, and fed ad libitum one of the following four rations in the first replication:

1. Ration with low-iodine and normal magnesium[1]. This ration also served as control for the rest of the ration treatments.

2. Ration with normal magnesium, but high iodine content of ten times the NRC requirement of 0.015mg/100gm diet. Iodine, as potassium iodide, was added to the low-iodine diet.

---

[1] The basal ration was the low iodine test diet supplied by the Nutritional Biochemicals Company, Cleveland, Ohio 44128.

3. Ration with high magnesium content of five times the NRC requirement of 40mg/100gm diet. Magnesium salt was added as magnesium oxide to the low-iodine test diet.

4. Ration with both high magnesium and high iodine added in proportions of five and ten times the requirement, respectively.

The second replication was identical to the first, except that high dietary potassium was substituted, as potassium iodide, at a level of ten times the requirement of 180mg/100gm diet, instead of the high magnesium. The detailed composition of the rations is given in Table I.

About thirty-five hours before killing on the last day, one rat from each ration and age group was dosed quantitatively, intraperitoneally, with 0.1ml (0.1uc) of carrier-free Mg^{28}, and placed in a metabolism cage for quantitative collection of feces and urine (Hansard and Comar, 1953).

Feces and urine samples were collected at three time intervals before killing, weighed or measured, and the Mg^{28} counted in an automatic scintillation counter. All dosed rats were sacrificed after the twelfth day on the rations and 35 hours after dosing, and the following individual samples were taken: blood, heart, spleen, liver, femur, kidney and gastrocnemius muscle. Samples were weighed, counted and chemically analyzed individually for Mg, Ca, K, Fe, Cu, Zn and Mn. All other rats from these treatments were killed on the twelfth or thirteenth day, and identical tissues were

TABLE I

AVERAGE MEAN RATION COMPOSITION OF YOUNG AND OLD RATS

	Proximate Analysis[a]						Minerals[b]						
	D.M.	Crude Proteins	Ash	E.E.	C. Fiber	N.F.E.	Mg	Ca	K	Zn	Fe	Cu	Mn
Basal Ration	89.94	21.13	2.05	0.66	0.24	65.86	26.83	727.75	84.93	1.59	1.67	0.41	0.44
High Mg Ration	89.94	21.13	2.05	0.66	0.24	65.86	164.94	727.75	84.93	1.59	1.67	0.41	0.44
High K Ration	89.94	21.13	2.05	0.66	0.24	65.86	26.83	727.75	961.9	1.59	1.67	0.41	0.44

[a] Average percent composition on air-dryed basis.

[b] All values expressed as mg/100 gm of feed.

taken for chemical determination of minerals. Blood from each treatment group and lot was taken and pooled for PBI and total mineral determination. Individual blood samples were also taken from each rat for hematocrit. Serum was separated from the blood by centrifugation after complete clotting. The serum was stored by freezing at 0.0°C for iodine determination.[2]

All chemical analyses were performed by atomic absorption spectrophotometer.[3]

---

[2]Tetrasorb-125(T-4 diagnostic kit). Abbott Laboratories, Radio-Pharmaceutical Products Division, North Chicago, Illinois.

[3]Perkin-Elmer Manual. Analytical Methods for Atomic Absorption Spectrophotometry. Perkin-Elmer, Norwalk, Connecticut.

CHAPTER IV

RESULTS AND DISCUSSION

Treatment effects on feed consumption by rats. Average feed consumption values of different rats are presented in Table II (adjusted to a 100-gm rat weight). From these data, it is evident that young rats consumed a greater amount of all feeds per gram body weight than did old rats, irrespective of temperature; actual feed consumption, however, was greater in the old rats. Young rats consumed about 86 percent more feed at 3° than at 23°C, compared to a relative increase of 43 percent for old rats. This was in agreement with the study of Treadwell et al. (1957), who found greater feed consumption for animals at 1° than at 25°C. However, since it was not mentioned, they probably did not observe such an increase in feed consumption for their immature rats in cold as compared to the increase for old rats. The results also agree with Hegsted et al. (1956) who found a 20 percent increase in feed consumption in cold; however, in the present experiment the observed increase in feed consumption in cold was about 52 percent. This figure on a 100 gm rat weight basis, however, amounted to 70 percent.

Young rats consumed 99 percent more feed at 3° than at 23°C when fed the basal low-iodine ration, whereas old rats did not show an increased consumption in cold. On addition of high iodine to the diet, young rats consumed about

TABLE II

MEAN DAILY FEED CONSUMPTION BY YOUNG AND OLD RATS (ADJUSTED TO 100-gm RAT WEIGHT), FED VARIOUS RATIONS AT 3° and 23°C

Ration	Low I N-Mg	High I N-Mg	Low I High Mg	High I High Mg	Low I High K	High I High K
Number of Rats	6	6	3	3	3	3
3±5°C Young	20.5	18.0	20.4	19.3	17.6	19.5
Number of Rats	6	6	3	3	3	3
23±1°C Young	10.3	10.4	11.3	11.2	9.5	9.5
Number of Rats	6	6	3	3	3	3
3±0.5°C Old	5.2	4.4	4.7	6.2	4.4	3.5
Number of Rats	6	6	3	3	3	3
23±1°C Old	5.2	3.0	2.8	4.6	3.1	2.1

12 percent less feed in cold, while no change occurred at room temperature (23°C). Similar values for old rats showed 14 percent and 42 percent reduced intakes at 3° and 23°C. respectively. No change in feed consumption occurred in young rats when high magnesium was fed in the ration, whereas old rats consumed 10 percent and 46 percent less at 3° and 23°C, respectively. Slight differences occurred in feed consumption of all rats fed the ration containing high iodine and high magnesium.

When high levels of potassium were fed to rats on low-iodine ration, 14 percent and 8 percent reduction in feed intake was observed for young rats in cold and room temperature, respectively. It was interesting to note that, while increasing the dietary iodine and potassium resulted in little change in the feed intake of young rats, old rats consumed 33 percent and 60 percent less feed at 3° and 23°C, respectively (Table II).

Differences in rat PBI values. It is observed in Table III that PBI values of the pooled serum of rats, on an average, were lower in cold than at room temperature. This may be explained by a greater rate of utilization (Rand et al., 1952) and disappearance from the serum and a lower iodine absorption from the intestine, especially when rat diet contained low levels of iodine. However, this did not agree with the work of Yousef et al. (1967), who reported increased PBI levels for cattle at 1°C exposure, although the rations used were not low

TABLE III

PROTEIN BOUND IODINE VALUES FROM RATS[a]

Ration	Low I N-Mg	High I N-Mg	Low I High Mg	High I High Mg	Low I High K	High I High K
Number of Rats	6	6	3	3	3	3
3±0.5°C Young	3.67	3.75	2.64	2.73	2.65	3.40
Number of Rats	6	6	3	3	3	3
23±1°C Young	3.62	4.27	4.00	4.80	3.64	2.06
Number of Rats	6	6	3	3	3	3
3±0.5°C Old	2.48	3.85	3.44	2.81	3.40	2.97
Number of Rats	6	6	3	3	3	3
23±1°C Old	4.08	3.02	4.00	4.09	3.22	5.54

[a] I^{125} labelled thyroxine method was used to determine iodine values. (mcg per 100 ml serum).

in iodine. At room temperature, young rats showed lower PBI values than old rats. Increase in the metabolic rate, however, is not dependent on a hyperthyroid state but on the presence of the hormone in the circulation (Sellers and You, 1950). It has been suggested that accurate measurement of "free" thyroxine is a far better index of metabolic status than serum PBI levels (Selekow and Robin, 1970), although "free" thyroxine is difficult to measure in the laboratory.

The high-iodine diet, however, increased PBI values, except for old rats at room temperature. When dietary magnesium was also raised along with iodine, the old rats did not appear to reflect a marked change in PBI values, whereas young rats showed decreased PBI values in cold, and increased values at room temperature. When rats were fed high iodine as well as high potassium, PBI values declined in young rats, but increased in old rats. High dietary magnesium or potassium did not produce a marked effect on PBI levels at 23°C, but in cold, PBI levels appeared to decrease in young rats, while increasing in old ones.

Effect on serum magnesium, potassium and other electrolytes. Table IV shows the concentration of different minerals in the serum of young and old rats, pooled for each dietary and temperature treatment. Average serum magnesium levels for all rats ranged from 0.75 to 2.75 mg/100 ml serum. Values were comparatively high for all rats fed high dietary magnesium with or without high iodine. The single exception was the case of

TABLE IV

MEAN SERUM ELECTROLYTES IN YOUNG AND OLD RATS FED DIFFERENT DIETS AT LOW AND ROOM TEMPERATURES

	Number of Rats	Young Rats							Old Rats						
		Mg[a]	Ca[a]	K[a]	Zn[b]	Fe[a]	Cu[a]	Mn[c]	Mg	Ca	K	Zn	Fe	Cu	Mn
At 3°C															
Basal	6	1.40	6.82	24.7	2.6	1.33	1.15	1.0	1.34	7.83	28.2	2.4	1.30	1.06	0.8
High Iodine	6	1.25	7.50	21.0	2.9	1.29	1.17	0.9	1.71	7.02	31.7	2.3	1.22	1.12	0.8
High Mg	3	1.68	6.04	28.1	2.7	1.34	1.21	0.6	1.89	8.36	25.8	2.3	1.30	1.16	1.2
High I, High Mg	3	2.75	6.00	21.8	3.6	1.34	1.27	0.6	2.35	8.15	34.1	2.9	1.37	1.16	0.8
High K	3	1.20	8.31	19.2	2.4	1.00	1.13	0.8	1.47	7.64	20.3	2.2	0.92	1.13	0.8
High I, High K	3	1.28	10.05	20.1	2.5	0.69	1.16	0.6	1.15	8.88	21.0	2.4	0.89	1.09	1.0
At 23°C															
Basal	6	2.11	10.09	27.8	2.7	1.31	1.06	0.9	1.37	8.60	21.2	2.3	1.07	1.00	0.6
High Iodine	6	1.41	8.22	21.7	2.6	1.41	1.01	0.7	1.74	7.85	24.3	2.4	1.50	1.03	0.8
High Mg	3	2.55	8.11	22.9	3.3	1.49	1.07	0.8	2.50	7.85	26.7	2.5	1.00	1.04	0.6
High I, High Mg	3	2.42	8.76	27.2	3.0	1.46	1.04	0.8	1.72	8.57	22.7	2.6	0.73	1.02	1.0
High K	3	1.00	7.07	23.6	2.8	1.00	1.09	0.4	1.27	8.55	32.3	2.1	0.73	1.02	0.6
High I, High K	3	0.75	5.45	22.9	2.5	1.00	1.07	0.6	1.00	8.52	28.9	2.0	0.69	1.04	0.6

[a]Values expressed as mg/100 ml of serum.

[b]Values expressed as mg/1000 ml of serum.

[c]Values expresses as ppm.

old rats fed the high iodine and high magnesium ration at 23°C. These results are in agreement with the work of McAleese et al. (1961), who observed higher serum magnesium levels in lambs on a normal magnesium ration, compared to lambs on a magnesium deficient ration. Similarly, decreased magnesium concentrations were observed in all rats fed high potassium in the ration with or without high iodine, except for old rats receiving the high-potassium diet in the cold. Effects of potassium were more evident at room temperature than in cold. These findings were in agreement with the report of Suttle and Field (1969), who noted decreased plasma magnesium levels in ewes by the increase of dietary potassium. The above-mentioned responses to higher dietary levels of iodine and magnesium, shown in increased serum magnesium levels, were slightly more marked in the cold (Axelrod and Bass, 1956).

Generally, serum calcium concentrations appeared to be higher when serum magnesium levels increased, and this response was more evident at lower ambient temperature. Calcium concentration was also higher for rats fed high dietary iodine when high potassium was added; high serum calcium was accompanied by somewhat lower serum magnesium levels. It may be pointed out that, at room temperature, all rats fed the above-mentioned ration showed the lowest serum concentrations of calcium and magnesium of all groups (Colby and Frye, 1951).

Potassium concentration in serum showed a wide variation ranging from 19.2 to 34.1 mg/100 ml serum, although no regular

age or treatment pattern was observed, and the data could not be used for valid conclusions.

Serum iron concentration appeared to increase and that of manganese to decrease in all rats fed the high potassium ration with or without high iodine. Neither temperature nor age produced marked changes in iron or concentration in rat serum.

In all rats, however, zinc concentration increased with an increase in serum magnesium. Copper was found to be in higher concentrations in cold-exposed rats. No other marked changes were observed in zinc and copper levels (Table IV).

Treatment effect on tissue concentration of magnesium. The data in Table V show the levels of magnesium in various selected rat tissues under different treatments. Highest concentration was found in rat femurs and ranged from 0.79 to 2.09 mg/gm femur. Generally, small differences in concentration were observed for the two temperatures, but this was not in agreement with the results of McAleese et al. (1961). The liver tissue of young rats showed a higher magnesium concentration per gram of tissue in cold than at 23°C. Neither ration nor age of rat revealed marked differences in liver magnesium concentration.

Old rats generally showed slightly higher magnesium tissue concentration than young rats, especially when fed high dietary magnesium with high iodine. However, femur

TABLE V

TREATMENTS EFFECTS UPON TISSUE MAGNESIUM CONCENTRATION OF YOUNG AND OLD RATS[e]
(mg per gm of tissue)

Ration	Young Rats					Old Rats				
	Heart	Liver	Spleen	Femur	Muscle	Heart	Liver	Spleen	Femur	Muscle
At 3°C										
Basal[a]	0.22±.02	0.22±.05	0.28±.05	0.90±.34	0.21±.05	0.17±.03	0.17±.02	0.20±.01	1.85±.24	0.22±.06
H I[b]	0.23±.03	0.24±.03	0.27±.04	1.03±.38	0.25±.03	0.17±.02	0.19±.03	0.21±.03	2.09±.72	0.18±.06
H Mg[c]	0.20±.00	0.20±.00	0.31±.00	0.93±.00	0.24±.00	0.22±.02	0.21±.04	0.19±.08	1.48±.20	0.18±.06
H I, H Mg	0.20±.02	0.25±.05	0.19±.01	1.39±.16	0.33±.03	0.20±.06	0.20±.00	0.26±.04	2.04±.11	0.26±.04
H K[d]	0.19±.01	0.20±.01	0.24±.02	1.00±.04	0.26±.02	0.14±.03	0.18±.00	1.20±.01	1.91±.19	0.21±.01
H I, H K	0.21±.00	0.20±.01	0.22±.01	1.15±.17	0.23±.01	0.17±.00	0.17±.01	0.19±.01	1.57±.05	0.20±.02
At 23°C										
Basal	0.20±.01	0.18±.03	0.23±.04	1.01±.27	0.24±.08	0.20±.03	0.23±.09	0.22±.03	1.42±.20	0.20±.06
H I	0.24±.05	0.16±.01	0.25±.02	1.01±.19	0.22±.05	0.15±.04	0.17±.03	0.21±.03	1.91±.37	0.23±.03
H Mg	0.22±.06	0.15±.01	0.24±.01	1.08±.15	0.26±.01	0.19±.02	0.18±.01	0.21±.11	1.90±.59	0.24±.03
H I, H Mg	0.24±.05	0.15±.02	0.31±.07	1.33±.27	0.26±.02	0.27±.06	0.19±.03	0.22±.02	2.01±.33	0.24±.06
H K	0.22±.03	0.18±.01	0.21±.01	0.80±.05	0.21±.01	0.16±.02	0.18±.03	0.17±.01	1.16±.35	0.18±.02
H I, H K	0.16±.02	0.18±.02	0.25±.01	1.28±.65	0.20±.01	0.16±.02	0.19±.02	0.18±.00	1.73±.32	0.19±.02

[a]Low I test diet with normal Mg and normal potassium.
[b]High I diet with normal Mg and normal potassium.
[c]Low I diet with high Mg and normal potassium.
[d]Low I diet with normal Mg and high potassium.
[e]Number of rats: 6 each in basal and high-iodine rations; 3 each in other ration treatments.

magnesium concentration was higher in young rats fed high potassium with high iodine than in young rats fed other rations. Young rats also revealed a greater spleen magnesium concentration than old rats, except for those rats fed the high iodine or high dietary magnesium in cold. Little variation in heart magnesium was noticed, except that old rats fed the high dietary potassium in cold showed comparatively low magnesium concentration. This was in agreement with the report of Seenappa (1971), but in the present experiment, liver magnesium did not change greatly.

Muscle tissue was higher in magnesium for rats on high dietary iodine with high magnesium, and the response was more evident in cold. No other clear changes were noticed in muscle magnesium concentration.

Generally, tissue concentration of magnesium increased in both age groups when high dietary iodine was included in the high magnesium ration, showing a greater utilization of magnesium in the presence of dietary iodine. This response was slightly higher in cold exposed rats.

Treatment effect on calcium and potassium tissue concentration. Data relating to calcium and potassium concentration in rat tissues are presented in Tables VI and VII, respectively.

Generally, old rats showed higher femur calcium concentrations than young rats, but did not show much temperature effect (McAleese and Forbes, 1961). In young rats, however, femur calcium concentration increased when high levels of potassium

TABLE VI

TREATMENTS EFFECTS UPON TISSUE CALCIUM CONCENTRATION IN YOUNG AND OLD RATS[e]
(mg per gm of tissue)

Ration	Young Rats					Old Rats				
	Heart	Liver	Spleen	Femur	Muscle	Heart	Liver	Spleen	Femur	Muscle
At 3°C										
Basal[a]	0.02±.01	0.003±.001	0.02±.01	77.5± 28.8	0.41±.58	0.03±0.1	0.003±.002	0.01±.01	132.6±17.6	0.06±.06
H I[b]	0.02±.01	0.007±.001	0.05±.03	91.4± 22.1	0.46±.33	0.04±.02	0.012±.010	0.03±.02	140.6±27.7	0.05±.02
H Mg[c]	0.05±.00	0.007±.001	0.07±.00	69.7± 0.0	0.68±.00	0.32±.01	0.003±.000	0.06±.05	128.0±16.7	0.14±.06
H I, H Mg	0.13±.06	0.005±.001	0.18±.14	145.6±108.8	0.30±.23	0.07±.02	0.022±.016	0.07±.05	170.3±16.0	0.27±.23
H K[d]	0.03±.01	0.003±.000	0.01±.01	75.6± 7.2	0.32±.28	0.02±.01	0.004±.002	0.03±.02	128.0± 9.8	0.03±.01
H I, H K	0.02±.01	0.004±.001	0.00±.00	109.3± 31.5	0.03±.01	0.02±.00	0.003±.000	0.01±.00	114.5± 0.0	0.03±.01
At 23°C										
Basal	0.03±.01	0.003±.002	0.01±.01	91.2± 22.3	0.05±.02	0.23±.01	0.003±.001	0.03±.02	103.0±16.7	0.03±.02
H I	0.03±.01	0.004±.001	0.02±.01	90.5± 21.2	0.04±.02	0.01±.00	0.002±.001	0.03±.02	135.8±18.5	0 02±.01
H Mg	0.04±.01	0.003±.001	0.01±.00	93.3± 22.4	0.21±.19	0.02±.01	0.003±.000	0.01±.00	125.6±32.3	0.02±.00
H I, H Mg	0.13±.06	0.004±.001	0.18±.14	145.5±108.8	0.30±.23	0.37±.00	0.002±.000	0.02±.02	102.3±35.4	0.03±.01
H K	0.04±.02	0.006±.002	0.01±.01	72.0± 5.5	0.25±.25	0.01±.00	0.003±.000	0.01±.00	88.3±24.8	0.04±.02
H I, H K	0.02±.01	0.004±.001	0.01±.01	85.6± 16.1	0.06±.04	0.02±.01	0.003±.000	0.02±.00	126.3±17.5	0.02±.00

[a]Low I test diet with normal Mg and normal potassium.

[b]High I diet with normal Mg and normal potassium.

[c]Low I diet with high Mg and normal potassium.

[d]Low I diet with normal Mg and high potassium.

[e]Number of rats: 6 each in basal and high iodine rations; 3 each in other ration treatments.

TABLE VII

TISSUE POTASSIUM CONCENTRATION FOR DIFFERENT TREATMENTS OF YOUNG AND OLD RATS[e]
(mg per gm of tissue)

Ration[b]	Number of Rats	Young Rats					Old Rats				
		Heart	Liver	Spleen	Femur	Muscle	Heart	Liver	Spleen	Femur	Muscle
At 3° C											
Basal[a]	6	1.91±.40	2.28±.50	3.13± .63	1.30± .48	2.11±.71	1.84± .48	1.97± .46	2.91± .37	0.86±.20	2.02±.52
H I[b]	6	2.00±.45	2.49±.34	2.89± .57	1.75± .65	2.00±.50	1.92± .36	2.23± .35	2.57± .89	0.89±.13	1.60±.78
H Mg[c]	3	1.17±.00	2.03±.00	4.64± .00	1.42± .00	1.27±.00	1.53± .26	2.24± .76	3.18±1.70	0.73±.33	1.85±.90
H I, H Mg	3	1.35±.08	2.37±.91	2.76± .79	1.85±1.17	2.54±.30	1.21±1.00	3.24±1.12	4.06± .39	1.54±.19	2.85±.61
H K[d]	3	2.14±.30	2.23±.15	2.96± .44	1.32± .08	2.44±.08	1.32± .44	2.03± .53	2.60± .60	0.67±.16	2.10±.17
H I, H K	3	1.90±.24	2.52±.11	3.24± .50	1.50± .00	2.58±.53	1.62± .24	1.24± .00	2.00± .33	0.55±.05	1.88±.24
At 23°C											
Basal[a]	6	1.71±.31	2.61±.63	2.87±1.12	1.63± .74	2.10±.36	1.39± .24	1.80± .65	2.23± .49	0.65±.23	1.83±.50
H I[b]	6	2.05±.35	2.47±.32	3.36± .50	1.67± .52	2.00±.56	1.17± .52	1.83± .25	2.32± .61	0.70±.23	2.17±.40
H Mg[c]	3	2.14±.43	2.60±.12	3.13± .35	1.75± .32	2.47±.53	1.65± .11	1.97± .24	2.35± .92	0.93±.24	2.55±.32
H I, H Mg	3	1.78±.26	2.70±.20	4.03± .70	1.71± .40	2.36±.06	1.72± .99	1.67± .36	2.48± .49	0.72±.29	2.23±.90
H K[d]	3	1.75±.31	2.35±.33	2.89± .48	0.80± .35	2.45±.14	1.33± .53	1.77± .08	1.84± .15	0.54±.13	1.96±.22
H I, H K	3	1.44±.14	2.18±.12	2.26± .57	0.70± .25	2.12±.10	1.09± .29	2.06± .36	1.44± .30	0.38±.08	1.77±.22

[a]Low I test diet with normal Mg and normal potassium.

[b]High I diet with normal Mg and normal potassium.

[c]Low I diet with high Mg and normal potassium.

[d]Low I diet with normal Mg and high potassium.

[e]Number of rats: 6 each in basal and high iodine rations; 3 each in other ration treatments.

with iodine were fed in cold. Calcium concentration was also elevated by feeding the basal low-iodine diet, with or without high magnesium, to young rats at room temperature. High dietary iodine, alone or with high magnesium, increased liver calcium concentration in all rats in cold. Moreover, almost all the young rats in cold had the highest calcium deposition in muscle tissue. At room temperature, old rats showed a more uniform muscle calcium level. In general, all rats reflected a higher muscle calcium concentration on high dietary magnesium, with or without high iodine, the exception being old rats at 23°C.

Tissue calcium concentrations were usually greater when high dietary iodine was combined with high magnesium than when high magnesium was fed with low dietary iodine.

Generally, liver and muscle tissues did not show a clear and considerable variation of potassium concentration, but even then it was more concentrated in livers of old rats in cold, compared to other rats. In the femur, however, young rats revealed a higher potassium concentration than old rats, with slight exception. Old rat femurs showed increased potassium concentration for the high-iodine, high-magnesium ration.

High dietary magnesium, with or without high iodine, showed decreased heart potassium concentration for all rats in cold; this result was not observed at 23°C. High dietary potassium with high iodine also appeared to decrease heart potassium in most rats, but the high potassium diet alone did not reflect

a marked change. It was interesting to observe that high dietary magnesium, with or without high iodine was reflected in an increased spleen potassium concentration, although a wider standard deviation was present, especially at 3°C.

Excretion of magnesium in young and old rats. Data in Table VIII, taken 35 hours following the intraperitoneal dosing of rats with 28-magnesium, indicate that most of the radio-magnesium excretion was in the urine. Stable magnesium excretion did not differ considerably in urine and feces, although young rats in cold appeared to excrete slightly more magnesium in feces than in urine.

Data also indicated that young rats on the basal low-iodine ration reflected no effect of ambient temperature on urinary magnesium excretion, while twice as much injected radio-magnesium appeared in the urine at room temperature than at 3°C. For the same rats, at room temperature, fecal excretion increased 52 percent and 300 percent for magnesium and radio-magnesium, respectively. In contrast, old rats on the basal low-iodine ration excreted 5 to 6 times more total urinary magnesium at room temperature. Fecal magnesium excretion also increased 6 times at 23°C, but fecal excretion of 28-Magnesium decreased.

When high iodine was added to the basal diet, total excretion of magnesium and radiomagnesium increased for all rats in cold, while at room temperature all rats showed

TABLE VIII

MAGNESIUM AND RADIOMAGNESIUM BALANCE DATA FROM RATS[c]

Ration	Intake Mg	Magnesium[a] Urine	%	Feces	%	Balance%	Radio-Magnesium[b] Urine	%	Feces	%	Balance%
Young Rats at 3°C											
Basal	7.43	2.57	34.5	5.61	75.5	-10.0	1.50	0.88	1.04	0.18	98.94
High I	5.63	3.11	55.2	4.83	85.8	-41.0	1.14	1.74	1.21	0.42	97.84
High I, High Mg	29.57	7.69	26.0	4.64	15.7	58.3	8.50	1.53	1.14	0.13	98.34
High K	6.84	6.12	89.4	2.45	35.0	-24.4	1.50	1.57	1.31	0.36	98.07
Young Rats at 23°C											
Basal I	3.13	1.13	35.9	1.65	52.7	111.4	7.60	1.90	0.56	0.06	98.04
High I	4.18	1.28	30.8	0.97	23.2	46.0	3.50	0.59	1.20	0.05	99.36
High I, High Mg	4.29	2.15	50.1	1.46	34.0	15.9	1.56	0.59	0.64	0.11	99.30
High K	4.06	1.79	44.0	3.49	85.9	-29.9	1.50	0.73	0.50	0.12	99.15
Old Rats at 3°C											
Basal	11.27	2.38	21.1	3.13	27.8	51.1	1.45	1.83	0.40	0.06	98.11
High I	6.02	2.96	49.2	2.65	44.0	6.8	1.60	1.73	0.40	0.12	98.15
High Mg	57.48	15.00	26.1	30.57	53.2	20.7	1.40	0.82	0.20	0.03	99.15
Old Rats at 23°C											
Basal	7.47	9.53	127.5	11.47	153.4	-180.9	0.90	0.66	1.30	0.29	99.05
High I	2.74	1.73	63.7	1.77	64.8	-28.5	0.22	0.11	0.60	0.11	99.78
High I, High Mg	45.93	2.31	5.0	7.02	15.2	79.8	0.93	0.62	0.03	0.01	99.37
High K	6.52	6.35	97.5	4.11	63.1	-60.6	0.70	0.70	1.57	0.36	98.94

[a]Values expressed as total mgs. in urine and feces for the 35 hour period, post-dosing of Mg 28.

[b]Values expressed as percent dose ^{28} Mg/gm x 10^{-1} in urine and feces.

[c]Number of rats: one per treatment.

decreased excretion values. Young rats fed high magnesium were not dosed with 28-magnesium. Old rats fed this ration in the cold, however, excreted about 50 percent less 28-magnesium, but more stable magnesium in urine and feces, when compared with the basal ration-fed rats. All rats fed high potassium were dosed with the isotope, except for the old rats in cold. This treatment did not reflect much change except that comparatively more total excretion of radiomagnesium occurred in cold than at room temperature, when the values were compared with the basal ration-fed rats. This finding did not agree with the study of Suttle and Field (1967), indicating a decreased output of magnesium in urine with a high potassium diet, although the ration was not low in iodine. On addition of high iodine to a high-potassium diet, more total magnesium appeared to be excreted from the body, whereas there was little change in 28-magnesium excretion (Sezelenye et al., 1968).

Excretion of other electrolytes. Results of intake and excretion of other selected minerals for different rats are presented in Table IX.

The data indicated that old rats fed the high-iodine ration, at either low or room temperature, excreted more total potassium than ingested. More potassium, however, was retained by young rats fed high potassium, irrespective of ambient temperatures. In all rats, the main route of potassium excretion was urinary.

TABLE IX

TREATMENT EFFECT UPON INTAKE AND EXCRETION VALUES OF SELECTED MINERALS IN YOUNG AND OLD RATS[d] DOSED WITH RADIOMAGNESIUM

Ration	Young Rats					
	K	Ca	Zn	Fe	Cu	Mn
At 3°C						
Basal	23.16[a]	198.46	0.436	0.45	0.112	0.119
	12.06[b]	36.14	0.029	0.03	0.007	0.006
	2.41[c]	255.64	0.921	0.11	0.008	0.111
High I	17.83	152.88	0.336	0.35	0.086	0.092
	13.16	51.04	0.040	0.13	0.014	0.013
	2.00	238.09	0.820	0.11	0.010	0.151
High I, High Mg	15.28	130.53	0.287	0.30	0.073	0.078
	3.58	13.90	0.014	0.00	0.004	0.003
	0.85	75.18	0.708	0.06	0.003	0.030
High K	245.30	185.64	0.408	0.43	0.104	0.111
	161.77	55.60	0.030	0.03	0.010	0.016
	2.94	165.31	0.632	0.08	0.026	0.503
At 23°C						
Basal	9.91	84.95	0.187	0.20	0.048	0.051
	5.21	15.86	0.011	0.01	0.002	0.004
	1.24	78.53	0.130	0.03	0.006	0.075
High I	13.25	113.56	0.249	0.26	0.064	0.068
	4.22	11.85	0.007	0.00	0.003	0.001
	1.06	54.62	0.054	0.04	0.004	0.055
High K	153.91	116.48	0.256	0.27	0.066	0.070
	69.05	15.20	0.005	0.02	0.002	0.007
	0.75	62.77	0.132	0.04	0.014	0.236
High I, High K	145.83	110.36	0.242	0.25	0.062	0.066
	53.33	16.74	0.013	0.06	0.003	0.005
	7.15	138.73	0.151	0.07	0.013	0.230

TABLE IX (continued)

Ration	Old Rats					
	K	Ca	Zn	Fe	Cu	Mn
At 3°C						
Basal	35.67[a]	305.76	0.672	0.70	0.172	0.184
	8.86[b]	14.64	0.012	0.04	0.010	0.010
	1.79[c]	219.75	0.300	0.10	0.013	0.141
High I	19.06	163.43	0.359	0.37	0.092	0.098
	132.73	26.78	0.015	0.02	0.011	0.014
	7.10	68.65	0.133	0.05	0.007	0.123
High Mg	29.59	253.71	0.557	0.58	0.143	0.153
	16.68	10.96	0.022	0.03	0.010	0.010
	2.75	233.92	0.401	0.07	0.030	0.497
At 23°C						
Basal	23.65	202.75	0.445	0.46	0.114	0.122
	10.40	13.02	0.014	0.02	0.004	0.005
	1.97	162.30	0.161	0.05	0.010	0.102
High I	8.66	74.25	0.163	0.17	0.042	0.045
	34.61	10.01	0.010	0.01	0.002	0.006
	0.41	61.37	0.080	0.02	0.009	0.161
High I, High Mg	23.65	202.75	0.445	0.465	0.114	0.122
	6.92	6.67	0.020	0.030	0.005	0.005
	2.07	100.53	0.100	0.05	0.008	0.089
High K	233.76	176.90	0.389	0.41	0.099	0.106
	96.70	14.32	0.025	0.04	0.005	0.011
	4.14	128.90	0.161	0.04	0.020	0.362

[a] Intake in mgs. for 35-hour period.

[b] Excretion in urine (mg).

[c] Excretion in Feces (mg).

[d] Number of rats: one for each treatment presented

Calcium was mostly excreted in feces, and, in general, low iodine diets resulted in higher calcium excretion from the body, especially for rats retained in cold.

Most of the excreted zinc was fecal for all rats and, in cold, more zinc was excreted than ingested. This response was further aggravated in cold by a high-iodine and high-magnesium ration.

Excretion of iron also chiefly fecal, but all rats showed a positive balance of this electrolyte. Copper also was in a positive 35-hour balance for all rats. Rats fed high iodine and high potassium reflected higher excretion of copper in the cold than at 23°C.

Manganese intake and excretion values did not reveal noticeable changes in excretion, except that more manganese appeared to be excreted by rats on a high potassium diet; this response was more evident in cold (Table IX).

Blood and tissue concentration of radiomagnesium. The percent of 28-magnesium/ gm x 10^{-1} and calculated specific activity values 35 hours after dosing are presented in Table X. Radiomagnesium concentration was greatest in liver, spleen, heart and kidneys, and mostly in that order. This was in agreement with the results of McAleese et al. (1961) for lambs. The turnover rate of 28-magnesium, however, was usually higher in liver, spleen, heart and kidneys, for all rats. Whole blood of young rats showed a higher percentage of 28-magnesium dose

TABLE X

PERCENT DOSE AND SPECIFIC ACTIVITY VALUES OF DIFFERENT ORGANS OF RATS[c] THIRTY FIVE HOURS AFTER INTRAPERITONEAL DOSING WITH 28-MAGNESIUM

	Young Rats								Old Rats						
Ration	Blood	Heart	Liver	Spleen	Femur	Muscle	Kidney	Ration	Blood	Heart	Liver	Spleen	Femur	Muscle	Kidney
At 3°C															
Basal	0.8[a]	2.3	7.1	3.2	0.9	1.2	1.9	Basal	0.04	0.6	1.0	1.1	0.6	0.4	0.8
	26.6[b]	10.4	49.3	8.9	3.8	12.5	9.3		2.2	4.8	6.4	5.4	0.2	1.2	4.9
High I	0.2	1.9	2.0	2.1	1.3	1.1	1.5	High I	0.1	0.9	1.1	1.0	0.5	0.3	0.7
	9.5	10.5	10.1	10.1	3.3	5.7	8.6		4.9	6.3	5.8	6.1	0.3	1.5	5.1
High K	0.2	1.1	1.2	1.5	2.7	1.0	2.8	High Mg	0.1	0.2	0.3	0.1	0.7	0.1	0.2
	6.7	6.2	5.8	5.3	2.7	4.3	5.4		1.8	0.9	2.1	1.6	0.4	0.8	1.1
High I,	0.1	0.5	0.6	0.7	0.2	0.7	0.5		—	—	—	—	—	—	—
High Mg	1.4	2.2	3.4	4.0	1.4	2.5	2.2								
At 23°C															
Basal	0.2	1.5	1.0	0.2	1.6	2.6	1.6	Basal	1.2	1.0	—	1.2	—	0.4	0.8
	5.4	7.6	5.5	9.6	1.4	6.5	22.1		60.4	5.3	—	4.8	—	1.5	5.1
High I	0.3	1.8	1.7	2.9	2.9	1.5	1.9	High I	0.2	0.9	1.3	1.3	—	0.4	0.5
	10.3	9.3	4.7	22.4	3.6	9.7	9.8		5.3	5.5	6.4	4.9	—	1.8	2.7
High K	0.1	0.8	0.9	1.1	1.5	0.4	0.7	High K	0.1	0.9	1.1	0.9	0.5	0.4	0.7
	7.0	4.2	5.1	5.6	1.7	2.0	4.4		5.4	7.9	8.3	6.4	0.3	1.8	7.2
High I,	0.3	1.7	2.0	2.0	3.0	1.0	1.6	High I,	0.2	0.3	0.3	0.4	0.2	0.2	0.5
High K	14.0	12.5	8.7	12.8	4.3	6.9	11.0	High Mg	5.3	0.8	2.6	2.5	0.1	1.2	3.5

[a]Percent dose $^{28}Mg/gm \times 10^{-1}$, corrected to 100 gm rat weight.

[b]Specific activity, calculated: $\frac{28\ Mg/gm \times 10^{-1}}{mg/gm\ Mg.}$, fresh basis.

[c]Number of rats: one per treatment.

retention than did that of old rats, especially in cold (McAleese et al., 1961), except for old rats fed the basal ration at 23°C. Blood accumulated radiomagnesium more rapidly at room temperature than in cold, a response more marked in old rats. In general, the blood turnover rate of 28-magnesium was higher for the rats fed the basal diet.

In cold, young rats showed a higher percent 28-magnesium dose retained in liver and spleen than old rats. For all rats, liver turnover rates were higher for basal ration than other rations in cold; but young rat spleens showed a higher turnover rate of 28-magnesium at room temperature.

It was interesting to note that a lower percent dose of 28-magnesium was retained in the heart of all rats fed the high magnesium ration, compared to other rations; the turnover rate of 28-magnesium was also low in these rats. Rats on high-iodine and high-potassium rations had a comparatively high turnover rate of 28-magnesium in heart.

The percent dose retained, 35 hours after dosing, was higher in bone and soft tissues of young rats than of old rats. The turnover rate of 28-magnesium was also higher in all young rat tissues. High-iodine ration seemed to increase the femur specific activity, expecially at 23°C, perhaps indicating the depletion and lability of bone magnesium (McAleese and Forbes, 1961). Temperature, however, did not appear to have a noticeable effect on the percent dose retention in rat muscle. Basal ration-fed rats had a higher percent dose of 28-magnesium retention in muscle tissue, possibly reflecting the low dietary iodine (hyperthyroid) effect on the magnesium in muscles.

Kidney 28-magnesium turnover rate at 23°C was higher for young rats than for old rats fed the basal ration. High iodine and high magnesium however, appeared to decrease the turnover rate in young rats. Kidney percent 28-magnesium dose retention was particularly high in young rats receiving the high-potassium ration in cold, but not at 23°C. No marked differences were observed in 28-magnesium retention in old rat kidneys. Kidney turnover rate of 28-magnesium decreased in old rats fed high magnesium, whereas it increased slightly on high dietary potassium (Table X).

Total 28-magnesium uptake in blood and organs. Data on the percent uptake of 28-magnesium for total blood and organ of rat (adjusted to 100-gm rat), shown in Table XI, showed young rats to have higher values than old ones, in general.

Liver and heart showed the greatest uptake for all rat treatments (McAleese et al., 1961), being higher in cold than at room temperature, particularly in young rats. Spleen and femurs of old rats had low figures compared with young rats. Kidneys also showed a similar pattern, although the response was greater in cold, perhaps reflecting a greater enzymatic activity in young rats at lower temperature. In cold, the blood and liver of all rats generally showed lower 28-magnesium uptake values, although this response in liver was greater for old rats. Blood uptake values in old rats were usually elevated by the high-iodine ration, irrespective of temperature. All

TABLE XI

PERCENT 28-MAGNESIUM UPTAKE OF DIFFERENT ORGANS OF YOUND AND OLD RATS[b]
THIRTY FIVE HOURS AFTER INTRAPERITONEL DOSING

Ration[a]	Heart	Liver	Spleen	Femur	Kidney	Blood	Ration[a]	Heart	Liver	Spleen	Femur	Kidney	Blood
Young Rats At 3°C							Young Rats At 23°C						
Basal	0.1806	3.80	0.0732	0.0104	0.3027	0.477	Basal	0.0905	0.472	0.059	0.057	0.220	0.101
High I	0.1255	0.86	0.0451	0.1117	0.2177	0.136	High I	0.0742	0.769	0.065	0.143	0.196	0.170
High K	0.0774	0.52	0.0396	0.1038	0.1653	0.118	High K	0.0302	0.409	0.026	0.064	0.078	0.116
High I, High Mg	0.0349	0.28	0.0200	0.0068	0.0652	0.020	High I, High Mg	0.0786	0.920	0.056	0.158	0.164	0.230
Old Rats At 3°C							Old Rats At 23°C						
Basal	0.005	0.302	0.015	0.017	0.057	0.117	Basal	0.020	———	0.011	———	0.029	0.460
High I	0.026	0.340	0.014	0.015	0.055	0.340	High I	0.019	0.404	0.008	———	0.013	0.910
High Mg	0.008	0.110	0.005	0.026	0.015	0.220	High K	0.019	0.350	0.012	0.015	0.021	0.515
							High Mg	0.011	0.127	0.011	0.009	0.043	0.420

[a] Basal - low iodine ration; H I - ration with high iodine; H Mg - high Mg in low iodine ration; H K - high potassium in low iodine ration; H I - H Mg - ration with high iodine and high magnesium; H I - H K - ration with high iodine and high potassium.

[b] Number of rats: one per treatment.

rats receiving high iodine generally showed a higher percent 28-magnesium uptake in the liver, spleen and femur. The high magnesium ration lowered these values for all rat livers. Rat kidneys reflected slightly higher uptake values for the basal low-iodine ration than for other rations.

Effect of temperature, age and diet upon tissue concentration of zinc and iron. Zinc and iron tissue concentrations are presented in Tables XII and XIII, respectively, and are discussed below in order of tissues.

Young rats had a higher zinc tissue concentration than old rats. Temperature effects in young rats were not marked for zinc. The high-iodine and high-magnesium ration was reflected in a higher concentration of heart zinc in cold than at room temperature. In contrast, at room temperature, heart zinc concentration increased in rats receiving high-magnesium ration without high iodine. Generally, heart iron was higher in young rats than in old rats in cold. These differences were not marked at room temperature.

Liver zinc and iron were more concentrated in cold-exposed rats. Other differences for liver tissue were not marked.

Femur iron levels were usually higher in young rats, irrespective of temperature. Zinc was more concentrated in femurs of rats receiving high dietary iodine, with or without high magnesium.

Spleen zinc concentration increased in all rats on a high-dietary iodine and high-potassium ration. In young rat

TABLE XII

TREATMENT EFFECT ON TISSUE ZINC CONCENTRATION[a] OF YOUNG AND OLD RATS

Ration[b]	Number of Rats	Young Rats					Old Rats				
		Heart	Liver	Spleen	Femur	Muscle	Heart	Liver	Spleen	Femur	Muscle
At 3°C											
Basal	6	3.65±1.17	2.25± .62	8.44±2.01	9.00±4.75	3.45± .80	2.46±1.55	2.41± .41	3.84±1.26	11.62±1.65	1.46± .59
H I	6	2.95±1.94	3.45±1.51	2.74± .34	15.05±5.70	4.34±1.24	2.31± .38	3.11± .70	5.08±3.09	11.96±1.19	1.73± .68
H Mg	3	3.07±0.00	2.06±0.00	11.57±0.00	13.66±0.00	5.56±0.00	2.42± .45	3.57± .60	3.39±1.60	9.06±1.32	1.27± .38
H I, H Mg	3	4.01± .14	4.60±2.4	6.94±3.18	18.51±2.0	6.63± .42	4.22±1.48	3.43± .21	4.09±1.60	13.8 ±1.63	2.13±1.04
H K	3	3.72± .29	2.67± .48	1.90± .13	10.69± .84	2.95±1.62	1.57± .59	2.31± .28	1.62± .14	11.29± .66	1.71± .66
H I, H K	3	3.68± .17	2.06± .25	8.63±5.51	12.64± .87	4.96±3.01	2.20±0.00	2.66± .42	6.08±1.11	10.58± .35	1.77± .48
At 23°C											
Basal	6	4.26±2.01	2.03± .70	2.30±1.04	13.60±4.64	2.10±1.03	2.27±1.01	2.03±1.08	3.07±1.28	11.48±3.80	1.48± .46
H I	6	2.46±2.06	1.87± .52	3.11±1.56	11.57±2.83	4.81±2.69	2.25± .88	2.56± .39	3.66±1.16	11.97±2.67	1.53± .47
H Mg	3	6.02±3.81	1.57± .47	6.88±6.01	17.13±0.00	1.45± .29	3.06± .17	2.57± .39	1.67±1.15	12.03±3.58	2.54±1.59
H I, H Mg	3	3.2 ±2.50	1.57± .23	5.05±2.92	19.53± .74	0.90± .21	2.02± .05	2.22± .60	2.95± .81	10.58± .98	2.05±1.07
H K	3	5.2 ±2.90	2.42± .96	1.82± .06	8.93±0.00	2.81±2.91	2.91±1.14	2.64± .90	1.57± .15	9.66±1.75	1.13± .24
H I, H K	3	1.37± .49	3.33±1.36	3.64±2.05	8.07± .86	1.28± .90	1.56± .31	2.12± .04	2.42±1.55	10.73±1.41	1.12± .50

[a] All values expressed as mg Zn/100 gm of tissue.

[b] Basal - Low iodine basal ration; H I - basal ration with high iodine; H Mg - basal ration with high magnesium; H K - basal ration with high potassium.

TABLE XIII

TREATMENT EFFECT ON TISSUE IRON CONCENTRATION[a] OF YOUNG AND OLD RATS

Ration[b]	Number of Rats	Young Rats					Old Rats				
		Heart	Liver	Spleen	Femur	Muscle	Heart	Liver	Spleen	Femur	Muscle
At 3°C											
Basal	6	14.3±8.8	4.7±1.1	17.8± 8.7	8.5±3.2	2.8±0.7	9.3±6.3	13.6± 7.4	102.8± 44.1	4.8±1.5	3.7±1.9
H I	6	12.8±5.2	4.1± .7	16.5± 8.4	5.6±2.2	4.7±2.9	10.8±5.7	9.2± 5.9	154.5± 91.9	3.7±1.2	2.1±1.3
H Mg	3	9.5±0.0	1.2±0.0	6.7± 0.0	7.0±0.0	3.6±0.0	4.6±2.5	14.4± 5.9	88.5± 51.7	2.5±0.7	0.9±0.3
H I, H Mg	3	6.9±2.6	3.5± .3	19.6± 9.1	6.3±2.6	2.6±0.9	4.6±3.1	9.6±11.3	96.0±100.6	6.2±3.1	2.6±0.3
H K	3	9.5±2.1	5.6±1.7	12.7± 2.2	6.9±2.2	2.5±0.1	8.3±2.1	20.5± .5	195.5± 80.2	3.6± .8	5.6±3.0
H I, H K	3	9.7±1.5	5.3± .9	12.0± 3.5	10.4±6.0	2.1±0.1	9.3± .2	13.9± .8	103.0± 76.6	4.1±0.5	2.6±1.0
At 23°C											
Basal	6	10.4±2.8	6.9±1.7	24.3±21.9	9.4±6.0	3.3±1.3	11.2±2.4	15.2± 6.5	138.3± 66.0	5.5±1.5	3.5±1.5
H I	6	13.3±3.2	6.6±2.5	20.7± 6.7	8.5±3.8	4.2±2.1	9.7±2.1	17.7± 7.4	189.0± 41.1	5.4±1.8	3.4±0.8
H Mg	3	10.8±6.4	3.0±1.0	26.3± 1.1	8.4±1.6	6.6±1.9	11.3±4.8	25.2± 9.7	113.0± 63.1	4.1±1.5	2.8±0.9
H I, H Mg	3	16.2±3.7	4.6±2.1	37.2± 5.9	12.5±2.3	3.9±0.6	9.1±4.5	11.9± 6.6	93.7± 71.3	7.3±3.0	3.0±0.0
H K	3	11.1±2.8	7.7±2.0	15.5± 2.8	7.9±3.3	2.1±0.6	10.1± .7	15.5± 3.2	81.2± 48.3	3.8±0.3	2.5±0.1
H I, H K	3	7.5±1.8	11.3±5.5		4.9±1.8	2.6±1.2	8.8±1.6	19.8± 1.1	119.5± 39.9	4.3±0.9	2.4±0.8

[a] All values expressed as Mg percent.

[b] Basal - low iodine basal ration; H I - basal ration with high iodine; H Mg - basal ration with high magnesium; H K - basal ration with high potassium.

spleens, zinc also increased for the high magnesium ration. Spleen iron was higher in young rats fed high dietary iodine with magnesium, compared with old rats, irrespective of ambient temperature, and a similar response appeared in old rats fed the high-iodine diet. High dietary potassium also showed such a response, but only in cold.

Muscle zinc levels were highest in young rats exposed to cold. Other variations in muscle zinc and muscle iron concentration were inconsistent.

In general, low iron concentrations were reflected in the heart, liver and spleen tissues of young rats receiving high dietary magnesium in cold, and, to a lesser extent, in old rats. High iodine and high magnesium ration produced increased femur iron levels, irrespective of age or temperature.

Treatment effect on copper and manganese concentrations in rat tissues. Copper and manganese tissue concentrations given in Tables XIV and XV, respectively, showed no marked differences in heart copper concentration, but, generally, young rats had slightly higher values than old rats. High dietary potassium produced lower heart copper levels in cold-exposed rats than in rats kept at 23°C.

Liver and muscle copper concentrations did not show important differences, although concentration appeared to be slightly decreased in rats fed high dietary iodine with or without high magnesium at room temperature. Moreover, young rats showed somewhat higher muscle copper concentration than old rats.

TABLE XIV

TREATMENT EFFECT ON TISSUE COPPER CONCENTRATION[a] OF RATS

Ration[b]	Number of Rats	Young Rats					Old Rats				
		Heart	Liver	Spleen	Femur	Muscle	Heart	Liver	Spleen	Femur	Muscle
At 3°C											
Basal	6	1.3± .4	0.8± .1	1.7±1.0	1.1±0.3	0.5± .1	1.0± .3	0.6± .1	0.8± .2	0.5±0.0	0.5± .1
H I	6	1.2±0.3	0.9± .3	1.9±1.0	1.1± .5	0.8± .3	1.0± .2	0.7± .1	0.9± .5	0.6± .1	0.4± .1
H Mg	3	1.4±0.0	0.5±0.0	3.7±0.0	1.3±0.0	1.1±0.0	0.8± .2	0.8± .2	0.5± .3	0.4±0.0	0.4± .1
H I, H Mg	3	1.2± .2	0.9± .6	2.4± .5	1.7± .1	1.6± .9	1.4± .1	0.8± .2	0.4± .3	0.8± .1	0.6± .1
H K	3	0.8± .1	1.2± .6	0.7± .1	0.7± .1	0.7± .1	0.7± .1	0.5± .0	0.6± .3	0.6± .1	0.3± .0
H I, H K	3	1.1± .3	0.7±0.0	0.7± .1	1.0± .2	0.4± .1	0.9± .1	0.4±0.0	0.6±0.0	0.7± .1	0.3±0.0
At 23°C											
Basal	6	1.2± .2	0.5± .2	1.2± .3	0.9± .4	0.6± .2	1.0± .2	0.5± .2	0.7± .2	0.4± .1	0.3± .1
H I	6	1.6±1.3	0.4± .1	0.8± .2	0.7± .2	0.8± .6	0.8± .2	0.5± .2	0.9± .2	0.5± .2	0.5± .2
H Mg	3	1.0± .3	0.3±0.0	1.6± .8	0.4± .1	0.8± .2	0.7± .1	0.4± .1	0.4± .2	0.5± .2	0.2± .1
H I, H Mg	3	1.8± .4	0.3±0.0	2.8±2.1	1.0± .1	0.6± .3	1.3± .7	0.3±0.0	0.7± .1	0.6± .3	0.5± .2
H K	3	1.0± .2	0.5±0.0	0.7± .2	0.6± .1	0.3±0.0	1.3± .7	0.6± .2	0.8± .2	0.5± .1	0.4± .1
H I, H K	3	1.0± .2	0.5± .1	1.1± .5	0.5± .1	0.4± .1	0.8± .2	0.6± .1	0.6± .1	0.6± .1	0.3± .0

[a] All values expressed as Mg percent.

[b] Basal - low iodine basal ration; H I - basal ration with high iodine; H Mg - basal ration with high magnesium; H K - basal ration with high potassium.

TABLE XV

TREATMENT EFFECT ON TISSUE MAGANESE CONCENTRATION[a] OF RATS

Ration[b]	Number of Rats	Young Rats					Old Rats				
		Heart	Liver	Spleen	Femur	Muscle	Heart	Liver	Spleen	Femur	Muscle
At 3°C											
Basal	6	0.22±.17	2.9± .7	0.20±.22	3.2±1.2	0.7± .3	0.13±.12	2.0± .4	0.17±.07	2.5± .5	0.7± .6
H I	6	0.29±.13	3.1± .2	0.75±.39	5.1±2.6	1.9± .5	0.11±.03	2.1± .3	0.30±.17	2.6± .4	0.9± .6
H Mg	3	0.36±.00	2.5±0.0	0.12±.00	8.4±0.0	2.6±0.0	0.11±.02	1.8± .5	0.13±.09	2.0± .2	0.6± .4
H I, H Mg	3	0.47±.19	2.8± .7	0.80±.44	6.9±3.0	3.0± .3	0.15±.03	2.3± .5	0.34±.05	3.5± .6	1.0± .7
H K	3	0.14±.06	2.7± .4	0.24±.05	2.9± .6	0.6±0.0	0.13±.04	2.4± .4	0.23±.00	2.8± .4	1.0± .3
H I, H K	3	0.19±.07	2.7± .3	0.36±.04	4.8± .4	0.7± .1	0.11±.03	2.1± .2	0.25±.05	3.1± .1	0.7± .1
At 23°C											
Basal	6	0.31±.15	2.5± .6	0.48±.27	5.1±2.2	2.0± .6	0.12±.05	1.8± .8	0.25±.10	2.4± .5	0.3± .1
H I	6	0.32±.25	2.2± .4	0.38±.12	3.7±1.4	1.1± .6	0.08±.03	2.0± .5	0.13±.04	3.0± .8	0.8± .5
H Mg	3	0.17±.07	2.2± .1	0.40±.13	3.4±1.6	1.2± .3	0.12±.07	1.5± .2	0.14±.07	2.5± .6	0.3± .1
H I, H Mg	3	0.16±.03	2.5± .1	0.60±.21	4.9±1.3	0.7± .1	0.06±.02	1.3± .2	0.22±.17	2.3± .1	0.4± .1
H K	3	0.18±.03	2.5± .5	0.20±.04	3.0± .4	0.6± .3	0.14±.07	2.5± .7	0.24±.10	2.1± .3	0.3± .1
H I, H K	3	0.18±.02	2.4± .1	0.29±.07	3.0± .6	0.6± .2	0.10±.04	2.3± .5	0.10±.04	2.2± .4	0.2±0.0

[a] All values expressed as parts per million

[b] Basal - low iodine basal ration; H I - ration with high iodine; H Mg - basal ration with high magnesium; H K - basal ration with high potassium.

Spleen copper concentration was higher in young rats receiving high dietary magnesium with or without high iodine.

Femur copper concentration was higher in cold-exposed rats, except for high potassium fed rats. Other differences in femur copper levels were less marked.

Tissue manganese concentration was higher in young rats, irrespective of temperature. This response was greater in rats fed high dietary iodine with or without high magnesium. In old rats, temperature did not show much influence on tissue manganese levels; muscle concentrations, however, were slightly higher at room temperature.

Hematocrit Values - Temperature did not produce a marked effect on hematocrit. However, old rats, on an average, had 45.5 percent hematocrit compared to 37.5 percent for young rats.

CRANES CREST

CHAPTER V

SUMMARY

Hypomagnesemic tetany has provided the impetus for investigation of metabolic interrelationships in various animals. The present study, using 96 male rats, was involved with magnesium behavior under cold stress as associated with age, serum protein bound iodine (PBI) levels and selected diets (low and high iodine in combination with normal or high levels of magnesium or potassium). The results of these studies indicated that:

Rats in cold generally consumed more feed, but the percent of increase was greater for young rats (per unit of body weight). Moreover, old rats on the high-iodine, high-potassium diet consumed less feed, especially at room temperature.

Rats on low iodine diets showed decreased serum PBI values in cold compared with room temperature, and values decreased in young rats receiving a high-potassium or a high-magnesium diet. High-potassium diets also decreased serum-magnesium levels, especially at the higher temperature. Serum zinc concentration increased with an increase in serum magnesium, irrespective of temperature. However, copper level in serum was higher in the cold-exposed rats.

Generally, tissue concentration of magnesium increased in all rats when high dietary iodine was combined with high magnesium, especially at the lower temperature, suggesting a greater

magnesium utilization in the presence of high dietary iodine. Muscle-calcium deposition increased at the lower temperature in young rats, and tissue calcium levels increased in rats consuming the high-iodine, high-magnesium diet. Potassium levels decreased in the heart and increased in the spleen of all cold-exposed rats fed the high-magnesium diet, irrespective of iodine content.

Kidney was the principal excretory route for both magnesium and 28-magnesium. On the normal magnesium ration, addition of iodine lowered retention of magnesium and 28-magnesium in cold-exposed rats. High dietary potassium decreased absorption and retention of magnesium and 28-magnesium, and this was reflected in lower tissue concentration, especially in the young rats. Turnover rate of 28-magnesium was higher in soft tissues and lower in bone.

Concentration of other minerals further reflected metabolic effects. Tissue zinc concentration was generally higher in young than in old rats, and liver, zinc and iron were more concentrated in rats exposed to cold. Spleen levels of zinc increased in all rats on the high-iodine, high-potassium diet. Young rats had higher femur iron and manganese levels, irrespective of temperature. Femur iron levels increased on the high-iodine, high-magnesium diet, irrespective of age or temperature, whereas femur copper concentration were higher in cold-exposed rats, except for those fed the high-potassium diet.

LITERATURE CITED

CRANES CREST

LITERATURE CITED

Aikawa, J. K. 1963. The role of magnesium in biologic processes. Charles C. Thomas Co., Springfield, Illinois.

Allcroft, W. M. 1947. Seasonal hypomagnesemia of the bovine without clinical symptoms. Brit. Vet. J. 103:75.

Anast, C., C. D. Aunaud, H. Rasmussen and A. Tenenhouse. 1967. Thyrocalcitonin and the response to parathyroid Hormone. J. Clin. Invest. 46:57.

Axelrod, D. R. and D. E. Bass. 1956. Electrolyte and acid base balance in hypothermia. Amer. J. Physiol. 186:31.

Baker, D. G. and E. A. Sellers. 1957. Electrolyte metabolism in the rat exposed to a low environmental temperature. Can. J. Biochem. Physiol. 35:631.

Barnes, B. A., G. G. Eddison and O. Cope. 1957. Preparation and bioassay of a low magnesium liquid diet for human consumption. Surgery 42:643.

Bartlett, S., B. B. Brown, A. S. Foot, S. J. Rowland, R. Allcroft and W. H. Parr. 1954. The influence of fertilizer treatment of grassland on the incidence of hypomagnesemia in milking cows. Brit. Vet. J. 110:3.

Berthaux, P., J. Paupe and Nguyen-the-Minh. 1960. Effects de la parathyroidectomie et d'un extract parathyroidien sur l'elimination urinaire du magnesium chezle rat blanc. Compt. Rend. Soc. Biol. 154:1759.

Blaxter, K. L. and R. F. McGill. 1956. Magnesium metabolism in cattle. Vet. Rev. Anot. 2:35.

Blaxter, K. L., B. Cowlishaw and J. A. F. Rook. 1960. Potassium and hypomagnesemic tetany in calves. Anim. Prod. 2:1.

Blumer, C. C., F. J. Madden and D. J. Walker. 1939. Hypomagnesemia, grass tetany or grass staggers in sheep. Austral. Vet. J. 15:24.

Booker, W. M., R. L. Hays, D. DaCosta, W. Jones, R. Hill and P. Titus. 1952. Analysis of the electrolyte changes in rat during cold stress. Fed. Proc. 11:15.

Brown, G. M., S. S. Bird, L. B. Boag, D. T. Delahaye, J. E. Green, J. D. Hatcher and J. Page. 1954. Blood volume and basic metabolic rates of eskimos. Metabolism 3:247.

Carrell, E. and M. Pechet. 1967. Stimulation of bone formation by inorganic phosphate and inhibition of bone resorption by thyrocalcitonin. J. Clin. Invest. 64:1043.

Colby, R. W. and C. M. Frye. 1951. Effect of feeding various levels of calcium, potassium and magnesium to rats. Amer. J. Physiol. 166:209.

Conley, C. L. and J. L. Nickerson. 1945. Effects of temperature change on water balance in man. Amer. J. Physiol. 143:573.

Conway, E. J. and D. Hingerty. 1946. The influence of adrenalectomy on muscle constituents. Biochem. J. 40:561.

Deb, C. and J. S. Hart. 1956. Hematological and body fluid adjustments during acclimation to a cold environment. Can. J. Biochem. Physiol. 34:959.

Dempsey, E. W. and E. B. Astwood. 1943 Determination of rate of thyroid hormone secretion at various environmental temperatures. Endocrin. 32:509.

Duncan, G. G. 1954. Diseases of Metabolism, 3rd ed. W. B. Saunders Co., Philadelphia, Pennsylvania.

Duncan, C. W., C. F. Huffman and C. S. Robinson. 1935. Magnesium studies in calves(I).J. Bio. Chem. 108:35.

Egdahl, R. H., D. H. Nelson and D. M. Hume. 1955. Effect of hypothermia on 17-hydroxycorticosteroid secretion in adrenal venous blood in the dog. Science 121:506.

Eichelberger, L. and F. C. McLean. 1942. The distribution of calcium and magnesium between the cells and the extracellular fluid of skeletal muscle and liver in dogs. J. Biol. Chem. 142:467.

Elin, R. J., W. D. Armstrong and L. Singer. 1970. Adrenal gland factors in magnesium deficient rats. Proc. Soc. Exp. Biol. Med. 542:47.

Elkinton, J. R. 1957. The role of magnesium in the body fluids. Clin. Chem. 3:319.

Ender, F., I. W. Dishington and A. Helgebestad. 1957. The magnesium problem in relation to the tetany paresis syndrome in dairy cows. Nord. Vet. Med. 9:881.

Field, A. C., J. W. McCollum and E. J. Butler. 1958. Studies on magnesium and ruminant nutrition. Brit. J. Nutr. 12:433.

Forbes, R. M. 1965. Mineral utilization in the rat (5). J. Nutr. 86:193.

Garcia, J. F., R. W. Belknap and S. F. Cook. 1957 Increase in red cell volume in response to long exposure to cold. Proc. Soc. Exp. Biol. Med. 95:242.

Garner, R. J. 1950. Availability of the magnesium of the grass to the ruminant. Nature 166:614.

Ginn, H. E., R. Cade, T. McCallum and M. Fregley. 1967. Aldosterone secretion in magnesium deficient rats. Endocrin. 80:969.

Gitelman, H. J., S. Kukolj and L. G. Welt. 1968. Inhibition of parathyroid gland activity by hypermagnesemia. Amer. J. Physiol. 215:483.

Green, H. H. 1939. Recent advances in our knowledge of diseases associated with mineral balance in the blood of ruminants. Vet. Rec. 51:1179.

Green, H. H. 1948. Major and minor mineral elements in relation to animal health and pasture management in the British Isles. Nat. Vet. Med. Assoc. Publ. 17:60.

Greenberg, D. M., S. P. Lucia, M. A. Mackay and E. V. Tufts. 1933. The magnesium content of the plasma and red corpuscles in human blood. J. Biol. Chem. 100:139.

Gudmundsson, T. V., I MacIntyre and H. A. Soliman. 1966. The isolation of thyrocalcitonin and a study of its effects in the rat. Proc. Roy. Soc. 164:460.

Hale, H. B. and R. B. Mefferd, Jr. 1958. Factorial study of environmentally induced metabolic changes in rats. Amer. J. Physiol. 194:469.

Hanna, S. 1961. Plasma magnesium in health and disease. J. Clin. Path. 14:410.

Hansard, S. L. and C. L. Comar. 1953. Radioisotope procedures with laboratory animals. Nucleonics 11:44.

Heaton, F. W. 1965. The parathyroid gland and magnesium metabolism in the rat. Clin. Sci. 28:543.

Heaton, F. W. and L. N. Pyrah. 1963. Magnesium metabolism in patients with parathyroid disorders. Clin. Sci. 25:475.

Hegsted, D. M., J. J. Vitale and H. McGarth. 1956. The effect of low temperature and dietary calcium upon magnesium requirements. J. Nutr. 58:175.

Hendricks, H. J. 1962. Some biochemical aspects of hypomagnesemic tetany. Ph.D. thesis, University of Utrecht (In J. Anim. Nutr. 23:90).

Herd, R. P. 1966. Fasting in relation to hypocalcemia in lactating cows and ewes. Austral. Vet. J. 42:269.

Heroux, O. and J. S. Hart. 1954. Adrenal cortical hormone requirement of warm and cold acclimated rats after adrenalectomy. Amer. J. Physiol. 178:449.

Holtkamp, D. E., R. M. Hill, B. B. Longwell, E. K. Rutledge and A. R. Buchanan. 1949. Failure of adrenal cortical hormones to protect against cold in young normal and adrenalectomized rats. Amer. J. Physiol. 156:368.

Ingram, D. L. and A. Slebodzinski. 1965. Oxygen consumption and thyroid gland activity during adaptation to high ambient temperatures in young pigs. Res. Vet. Sci. 6:522.

Jones, L. M. 1954. Veterinary Pharmacology and Therapeutics. Iowa State College Press, Ames, Iowa.

Jones, K. H. and P. Fourman. 1966. Effects of infusion of magnesium and of calcium in parathyroid insufficiency. Clin. Sci. 30:139.

Kruse, H. D., E. R. Orent and E. V. McCollum. 1932. Studies on magnesium deficiency in animals: I-Symptomatology resulting from magnesium deficiency. J. Biol. Chem. 96:519.

Kunkel, H. O. and P. B. Pearson. 1948. Quantitative requirement of the rat for magnesium. Arch. Biochem. 18:461.

Kunkel, H. O., K. H. Burns and B. J. Camp. 1953. A study of sheep fed high levels of potassium bicarbonate with particular reference to induced hypomagnesemia. J. Animal Sci. 12:451.

LeBlond, C. P. and J. Gross. 1943. Effects of thyroidectomy on resistance to low environmental temperature. Endocrin. 33:155.

LeBlond, C. P., J. Gross, W. Peacock and R. D. Evans. 1944. Metabolism of radio-iodine in the rat-thyroid of rats exposed to high or low temperatures. Amer. J. Physiol. 140:671.

Leech, F. B. and G. L. Bailey. 1953. The effect on the health of lactating cows of treatment with galactopoietic doses of thyroxine or iodinated casein. J. Agric. Sci. 43:236.

Leffel, E. C., K. R. Mason and J. C. Shaw. 1958. The experimental production of hypomagnesemic tetany in cattle. J. Anim. Sci. 17:1182.

MacDonald, D. C. and A. D. Care. 1959. Excretion of labelled magnesium by the sheep. Nature 184:736.

MacIntyre, I., S. Bess and V. A. Troughton. 1963. Parathyroid hormone and magnesium hemostasis. Nature 198:1058.

MacIntyre. I., S. Hanna and K. A. K. North. 1961. Magnesium metabolism in parathyroid disease. Brit. Med. J. 2:1253.

MacManus. J., F. W. Heaton and P. W. Lucas. 1971. A Decreased response to parathyroid hormone in magnesium deficiency. J. Endocrin. 49:253.

Maley, G. F. 1957. Phosphorylations associated with the oxidation of external reduced di-phosphopyridine nucleotide by rat-liver mitochondria. J. Biol. Chem. 224:1029.

Marshak, R. R. 1958. Some metabolic derangements associated with magnesium metabolism in cattle. J. Amer. Vet. Med. Assoc. 133:539.

Marshak, R. R. 1959. The role of magnesium in the tetany syndromes of cattle. In Magnesium and Agriculture (proc. of the symp.).

McAleese, D. M. and R. M. Forbes. 1959. Experimental production of magnesium deficiency in lambs on a diet containing roughage. Nature 184:2025.

McAleese, D. M. and R. M. Forbes. 1961. The requirements and tissue distribution of magnesium in the rat as influenced by environmental temperature and dietary calcium. J. Nutr. 73:94.

McAleese, D. M., M. C. Bell and R. M. Forbes. 1961. Magnesium-28 studies in lambs. J. Nutr. 74:505.

Moodie, E. W. 1968. The effect of posterior pituitary hormone on the calcium, magnesium and phosphate and chloride metabolism of sheep. Quart. J. Exp. Physiol. 53:250.

Neubeiser, R. E. 1958. A study of magnesium and body fluids of the rat during cold acclimation. Masters thesis, University of Missouri, Columbia, Missouri.

Odell, D., E. E. Hatfield, W. C. Shrewsberry, M. E. Gibson and R. MacVicar. 1952. Effect of high dietary potassium on sheep. J. Anim. Sci. 11:790.

Parr, W. H. 1957. Hypomagnesemic tetany in calves fed on milk diets. Vet. Rec. 69:71.

Platner, W. S. 1950. Effects of low temperature on magnesium content of blood, body fluids and tissues of gold fish and and turtle. Amer. J. Physiol. 161:399

Platner, W. S. 1960. Electrolytes in acclimation to cold. Fed Proc. 19:130.

Platner, W. S. and M. J. Hosko, Jr. 1953. Mobility of serum magnesium in hypothermia. Amer. J. Physiol. 174:273.

Pleshchitser, A. La. 1958. Biological role of magnesium. Clin. Chem. 4:429.

Rand, C. G., D. S. Riggs and N. B. Talbet. 1952. The influence of environmental temperatures on the metabolism of the thyroid hormone in the rat. Endocrin. 51:562.

Randall, R. E. Jr., E. C. Ressmeisl and K. H. Bleifer. 1959. Magnesium depletion in man. Ann. Int. Med. 50:257.

Richer, C. L., R. Veilleux and P. Bois. 1967. Effects of magnesium deficiency on adrenal function in rats. Rev. Canad. Biol. 26:351.

Richer, C. L., R. Veilleux and P. Bois. 1968. Effect of magnesium deficiency on corticosterone in rats. Endocrin. 82:954.

Roberts, B., J. J. Murphy, L. Miller and O. Resenthal. 1954. The effect of parathyroid hormone upon serum levels and urinary excretion of magnesium. Surg. Forum 5:509.

Redbard, S., H. Saiki and A. Malin. 1950. Body fluid redistribution in induced hypothermia. Fed. Proc. 9:107.

Scott, D. and A. Dobson. 1965. Aldosterone and the metabolism of magnesium and other minerals in the sheep. Quart. J. Exp. Physiol. 50:42.

Seenappa, T. 1971. Magnesium interrelationships in monogastric and ruminant animals. Ph.D. dissertation, University of Tennessee, Knoxville, Tennessee.

Selekow, A. H. and N. I. Robin. 1970. The diagnosis and management of common thyroid diseases. J. Maine Med. Assoc. 61:199.

Sellers, E. A., and R. W. You. 1950. Role of thyroid in metabolic responses to a cold environment. Amer. J. Physiol. 163:81.

Sellers, E. A., S. S. You and N. Thomas. 1951. Acclimatization and survival of rats in the cold: Effect of clipping, of adrenalectomy and of thyroidectomy. Amer. J. Physiol. 161:481.

Selye, H. 1937. Studies on adaptation. Endocrin. 21:169.

Silberg, B. N., N. W. Carter and D. W. Seldin. 1965. Magnesium excretion in response to parathyroidectomy and acid loads. Clin. Res. 13:46.

Smith, R. H. 1957. Calcium and magnesium metabolism in calves. Biochem. J. 67:472.

Smith, W. O. and J. F. Hammerston. 1959. Intracellular magnesium in delirium tremens and uremia. Amer. J. Med. Sci. 273:413.

Stewart, J. and J. W. S. Reith. 1956. The effect of magnesium lining on the magnesium content of the pasture and the blood level of magnesium in cows. J. Comp. Path. Therap. 66:1.

Suttle, N. F. and A. C. Field. 1967. Studies on magnesium in ruminant nutrition. Brit. J. Nutr, 21:819.

Suttle, N. F. and A. C. Field. 1969. Studies on magnesium in ruminant nutrition. Brit. J. Nutr. 23:81.

Swan, J. B. and N. D. Jamieson. 1956. Studies on metabolic disorders in dairy cows. N. Z. J. Sci. Tech. 38:363.

Szelenyi, I., Libok Nam, J. Rigo, E. Nemesanszky, G. Simon and E. Posch. 1968. Magnesium metabolism and thyroid function. Biol. Abstr. 49:77463.

Tapley, D. F. and C. J. Cooper. 1956. The effect of thyroxine and related compounds on oxydative phosphorylation. J. Biol. Chem. 222:341.

Termouth, J. H. and A. W. Beattie. 1970. A note on the voluntary feed consumption and the Na-K ratio of sheep after shearing. Anim. Prod. 12:343.

Tipton, S. R., M. J. Leath, I. H. Tipton and W. L. Nixon. 1946. The effect of feeding thyroid substance on the activation of siccinoxidase and cytochrome oxidase in the liver tissue of rats. Amer. J. Physiol. 145:693.

Todd, J. R. 1969. Magnesium metabolism in ruminants. In Trace Mineral Studies With Isotopes in Domestic Animals. International Atomic Energy Agency, Vienna 131.

Treadwell, C. R., D. F. Flick and G. V. Vahouny. 1957. Nutrition studies in the cold. I. Influence of diet and low environmental temperature on growth and on the lipid content of livers in the rat. J. Nutr. 63:611.

Tyslowitz, R. and E. B. Artwood. 1942. Influence of pituitary and adrenal cortex on resistance to low environmental temperature. Amer. J. Physiol. 136:22.

Udall, R. H. 1947. Low blood magnesium and associated tetany occuring in cattle in the winter. Cornell Vet. 37:314.

Vitale, J. J., D. M. Hegsted, M. Nakamura and P. Connors. 1957a. The effect of thyroxine on magnesium requirement. J. Biol. Chem. 226:597.

Vitale, J. J., M. Nakamura and D. M. Hegsted. 1957b. The effect of magnesium deficiency on oxidative phosphorylation. J. Biol. Chem. 228:573.

Vitale, J. J., D. M. Hegsted and E. E. Hellerstein. 1959. Some aspects of magnesium metabolism in animals. In Magnesium and Agriculture. (Proc. of the symp.)

Vohnout, K., S. L. Hansard and E. L. Morton. 1968. Measurement of thyroxine values and degradation in sheep. Amer. J. Vet. Res. 29:657.

Wacker, W. E. C. and B. L. Vallee. 1958. Magnesium metabolism. New Eng. J. Med. 259:431.

Wallach, S., J. V. Bellevia, J. Schorr and A. Schaffer. 1966. Tissue distribution of electrolyte Ca-47 and Mg-28 in experimental hyper- and hypo-parathyroidism. Endocrin. 78:16.

You, R. W. and E. A. Sellers. 1951. Increased oxygen consumption and succinoxidase activity of liver tissue after exposure of rats to cold. Endocrin. 49:374.

Yousef, M. K., H. H. Kibler and H. D. Johnson. 1967. Thyroid activity and heat production in cattle following sudden ambient temperature changes. J. Anim. Sci. 26:142.

Zwemer, R. L. and R. C. Sullivan. 1934. Blood chemistry of adrenal insufficiency in cats. Endocrin. 18:97.

CRANES CREST

VITA

Mohan Chandra Sanwal, the second youngest child of Sri Padma Datt and Srimati Parvati Sanwal, was born in Nainital, Uttar Pradesh, India, on July 5, 1945. He attended elementary and junior high school at Nainital, and was graduated from Government Intermediate College at Almora, in 1962. In July, 1962, he entered the College of Veterinary Medicine, Uttar Pradesh Agricultural University, Pantnagar, from which he received the degree Bachelor of Veterinary Science and Animal Husbandry in 1966. Following his graduation, he was employed by the Indian Veterinary Research Institute as a Research Associate in Microbiology, stationed at Mukteswar-Kumaon, where he remained until January, 1970, at which time he went to the United States for further study. He enrolled in a program leading to the Master of Science in Animal Husbandry with a major in Animal Nutrition, at The University of Tennessee, Knoxville, receiving the degree in December, 1971. He is a member of Phi Sigma and Gamma Sigma Delta, national honor societies.