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A Study of Dietary Calcium and Phosphorus Intakes in Relation to Residual Ridge Resorption

Rita L. Sørensen

Abstract

A STUDY OF DIETARY CALCIUM AND PHOSPHORUS INTAKES IN RELATION TO RESIDUAL RIDGE RESORPTION

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Resorption of alveolar bone, a characteristic observed in periodontal disease, in the totally edentulous mouth and in generalized osteoporosis, is a common world-wide phenomenon in man. Calcium deficiency and calcium-phosphorus imbalance are implicated as plausible factors in all three instances.

A compilation of recent investigations strongly suggests that oral bone loss, whether in periodontal disease or in the residual ridges, is an early manifestation of osteoporosis; and that osteoporosis, in general, is associated with disturbed calcium homeostasis.

This study, patterned after that of Wical and Swoope, was conducted on 55 subjects who had been totally edentulous for at least three years.

All subjects were classified according to degree of residual ridge resorption as measured in each individual's panoramic radiograph of the jaw. Group I represents the 22 subjects with minimal resorption, and Group II includes the 33 subjects with severe resorption.

Each participant kept a written 7 day meal record which was analyzed by a computer programmed for Agriculture Handbook No. 8.

The individual intakes covered a wide range of variation with considerable overlapping of the two groups. A comparison of the two groups by statistical analysis showed a significant difference between the mean daily intakes of both calcium ($p < .01$) and phosphorus ($p < .001$), but no noticeable difference between the means of the calcium-to-phosphorus ratios. However, a highly significant correlation ($p < .0005$) was noted in a three variable test wherein, each individual's intake of calcium and calcium-to-phosphorus ratio were compared with the degree of resorption.

These findings support the view that either a low intake of calcium or an excess of phosphorus in the diet contributes to the resorption of alveolar bone and that the problem is compounded when both conditions occur simultaneously.

Further analysis compared sex with resorption; sex with age; and age with resorption. The association between sex and resorption proved significant ($p < .01$) with 70 percent of the women but only 40 percent of the men suffering severe bone loss. The association between sex and age and between resorption and age was not significant except that the tests between sex and age showed a slight decrease in association with increasing age while those between resorption and age revealed a slight increase.

These results agree with the observation that oral bone loss is more prevalent among women than men; but disagree with the assumption that resorption of residual ridges is a "normal" part of aging.

LOMA LINDA UNIVERSITY

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A STUDY OF DIETARY CALCIUM AND PHOSPHORUS INTAKES IN RELATION TO RESIDUAL RIDGE RESORPTION

by

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Each person whose signature appears below certifies that this thesis in his/her opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

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INTRODUCTION

Resorption of alveolar bone is a common, world-wide phenomenon in man. This problem is first evident in the recession of the part of the mandible and the maxilla that surrounds and supports the teeth. This recession of the upper and lower jawbones is a characteristic of severe periodontal disease which is the leading cause for the loss of teeth in persons past the age of 30.

When the natural teeth are lost from any cause, the edentulous jaws suffer, in most cases, a progressive reduction in size due to the continuing demineralization of bone. The residual ridges of alveolar bone remaining after the loss of teeth may be completely resorbed. The ability of an edentulous patient to wear and tolerate artificial dentures is directly affected by this resorption of the denture-supporting bone structure.

The problem of oral bone loss is so common that it has long been accepted as a "normal" part of aging.[1,2] Atwood,[3] however, considers residual ridge resorption (RRR) a major oral disease which is chronic, progressive, irreversible, and disabling. Millions of edentulous patients suffer physical, social, psychological, and economic distress as a result of this disease.[3]

The etiology of this degenerative condition is not yet completely understood, but the origin is probably multifactorial.[3-6] In the past, most dentists have assumed that atrophy of the edentulous jaws which they observed was due to local and mechanical factors such as disuse, pressure from dentures or local irritation/inflammation.[7-9]

Recent evidence, however, suggests that the resorption of alveolar bone is, fundamentally, due to systemic causes. Krook and others[10] have proposed that the loss of alveolar bone is an early sign of general osteoporosis. It is very likely that the loss of bone in periodontal disease, in the reduction of residual ridges, and in generalized osteoporosis is due to the same systemic factors.[10-13]

Wical and Swoope[14] state: "Among the many recognized systemic influences which affect the resistance and resorption of bone, calcium deficiencies and calcium-phosphorus imbalances have been specifically implicated as contributing factors in the pathogensis of alveolar bone destruction and osteoporosis."

These investigators compared the dietary calcium and phosphorus intakes with the alveolar bone condition of 44 edentulous subjects, and found a positive correlation between low calcium intake, low calcium/phosphorus ratios, and excessive bone resorption.

The objective of the research project reported herein, was to continue the study of the possible correlations between dietary calcium and phosphorus and the degree of resorption of alveolar bone. The method is patterned after the study of Wical and Swoope.[14]

REVIEW OF LITERATURE

Physiological Roles of Calcium and Phosphorus

Calcium is the most abundant mineral element in the body and phosphorus is the second. Over ninety-nine percent of the calcium and seventy to eighty percent of the phosphorus are in the bones and teeth. Non-skeletal calcium is found mainly in the blood and extracellular fluid with very little in the soft tissues and organs. Although relatively inert chemically, calcium is found in combination with proteins or in the ionized form. Ionized calcium is of great importance in the coagulation of blood, in the regulation of cardiac function and muscle irritability, in nerve transmission, in the activation of certain enzymes essential to metabolism and in the permeability of membranes.[15,16]

Non-skeletal phosphorus is found mainly in the soft tissues, with some phosphorus in every cell. It is very reactive chemically and imparts this characteristic to the compounds it forms. About ten percent of the phosphorus in the body is in combination with proteins, lipids, carbohydrates and other compounds in blood and muscle. As inorganic phosphate, phosphorus serves to maintain the acid-base balance of the blood; in the form of phosphate esters, it is important in the transfer of energy. Phosphorus is also an essential constituent of nucleic acids and nucleoproteins which are important in reproduction, transmission of hereditary traits, cell devision, and protein synthesis.[15,16]

Requirements for Calcium

That the body needs to be supplied with calcium and phosphorus is not questioned; how much is needed is a matter of debate. The problem of human calcium requirements has been under investigation for at least a century.[17] The principal means of assessment has been the balance method. Oral intake is compared with kidney, intestinal and dermal output. As only 20 to 40 percent of the calcium intake is absorbed,[15] an absorption factor of 30 to 35 percent is used in calculating the estimated body need.

When the estimated absorbed intake is equal to the estimated total output, calcium is said to be in balance. Calcium is said to be in positive balance when the adjusted intake is in excess of the output and in negative balance when the output is greater.

Body losses vary widely among individuals. Leitch and Aitken[18] found calcium excretion to range from 150-300 mg/day: Whedon's work[19] shows an average loss of 380 mg/day. Using an absorption factor of 35 percent, the daily requirements were calculated to be 430-860 mg/day for the first findings and 1060 mg/day for the second.

Allowances are set in accord with an amount estimated to maintain positive calcium balance for a given population. In the United States, the National Research Council[20] recommended intake levels that allow for maximum dividends in the maintenance and promotion of health. To allow adequate calcium for a satisfactory rate of growth, the Council set a daily minimum allowance of 800 mg for children aged one through ten; 1200 mg for those between eleven and nineteen years old; and 800 mg for adults except during pregnancy and lactation when the recommended intake is 1200 mg.

The FAO/WHO Expert Group[21] reported 400 to 500 mg calcium per day as the suggested practical allowance for adults. To arrive at their conclusion, they took into consideration the availability of calcium in the diets of general populations.

It is well to note, that in many countries where the available food supply is low in calcium, the climate is warm and sunny. It is an accepted fact that Vitamin D enhances the absorption of calcium.

<u>Requirements for Phosphorus</u>

Relatively little information is available for the human requirements of phosphorus. From his balance experiments, Sherman[22] derived that for an adult of 70 kg body weight, the need averages 0.88 g per day. The U. S. Food and Nutrition Board of the National Research Council states "Available evidence indicates that phosphorus allowances should be at least equal to those for calcium in the diets of children and of women during the latter part of pregnancy and during lactation. In the case of other adults the allowances should be approximately 1.5 times those for calcium. In general, it is safe to assume that if the calcium and protein needs are met through common foods, the phosphorus requirements also will be covered, because the common foods richest in calcium and protein are also the best sources of phosphorus."(23)

<u>The Calcium-to-Phosphorus Ratio (Ca/P)</u>

The amounts of calcium and phosphorus in the diet have an important relationship with each other. An excess of either element increases the excretion of the other.[16] The calcium/phosphorus ratio is important in ossification. In children, the product of serum Ca x P is normally 50 mg/100 ml; in rickets, this product may be less than 30.[16]

Concerning adults, Hegsted[24] states: "It appears likely that the importance of the calcium:phosphorus ration as a practical problem has been over-emphasized." However, Henrikson,[25] Krook and others[11] claim that a low intake of calcium and/or excess phosphorus causes bone resorption in excess of bone formation. Draper[26] and Krishnaro[27] and colleagues from their work on mice and rats concluded that Ca/P ratios lower than 2: 1 accelerate the rate of bone resorption in adult rats; and that the resorption rate may be arrested by reducing phosphorus intake during senescence. Jowsey[28] reports that the Ca/P ratio is more important as a cause for bone loss than the intake of either mineral.

Utilization of Calcium and Phosphorus

While dietary calcium is important as the source for the body's supply of calcium, the level of intake is not as pertinent to positive calcium balance as is the degree of utilization. The term 'utilization' indicates the relative amount of a nutrient that the body is able to absorb from the food and to make use of.[15] The amounts retained in the body may be used in the maintenance of tissues or for storage.

The degree of absorption of both calcium and phosphorus varies within individuals and under different conditions. Both elements must be set free from organic combinations and be in soluble form. It is estimated that 70 percent of the phosphorus and 20-40 percent of the calcium is absorbed from a mixed diet under ordinary conditions.[15]

Numerous factors affect the actual amount of the calcium that is absorbed. The degree of absorption is closely associated with need. Times of particular need are during growth, pregnancy, lactation and healing of fractures. Those on low intakes have greater absorption than those on higher levels. Vitamin D enhances the absorption of calcium from the intestine.[29] 15 percent of dietary calcium is absorbed on a high-protein diet and 5 percent on a low-protein diet.[16] Normal digestive activity and motility favor absorption as does an acid media in the upper intestinal tract. Lactose facilitates absorption by the formation of lactic acid.[30]

Factors that hinder the absorption of calcium include: an alkaline media in the intestinal tract; high fiber content in the diet and excess use of laxatives; the formation of insoluble compounds by the reaction of calcium with oxalates from certain leafy vegetables, with phytate from cereals, and with unabsorbed fatty acids.

In some recent studies, investigators have shown how retention of calcium can be affected. Johnson, Walker, Chander and others[31-33] demonstrated in their works that high protein intakes have a detrimental effect of calcium retention. Draper and his associates, in their experiments with aging rats, found that the cumulative excretion of calcium was 16 percent and 37 percent greater in the rats who consumed diets of 0.6 percent and 1.2 percent phosphorus, respectively, as compared to those on the 0.3 percent phosphorus diets.[26] The dietary calcium not absorbed in the intestine is excreted in the feces[24] and that not retained in the serum is eliminated in the urine. The retention of phosphorus is characteristic of renal tubular deficiency and a prominent cause of acidosis.

The Role of Parathyroid Hormone

While important to meeting the body's needs, the dietary intake of calcium is not the controlling factor for the concentration of calcium ions in the serum: nor is the amount of calcium actually utilized. Rather, it is the primary function of the parathyroid glands to regulate the calcium content in the serum to remain within its normal range of 9.0-11.0 mg/100 ml. The secretion of the parathyroid hormone (PTH) is subject to a negative feedback mechanism relating to the concentration of ionized calcium in the plasma. It is not affected, however, by the concentration of serum phosphate ions.

Other sites of action for the parathyroid hormone are the kidney and the intestine. In the kidney, PTH affects the tubular reabsorption of calcium and the reabsorption and secretion of phosphorus. The presence of PTH in the intestine increases the rate of absorption of calcium.[16]

Both Draper and associates[26] and Laflamme and Jowsey[34] have demonstrated in laboratory animals that excess dietary phosphorus has deleterious effects on the integrity of adult bone by a mechanism involving parathyroid hormone.

Homeostatic Equilibrium of Calcium

The calcium in the blood is in dynamic equilibrium with the calcium in the skeleton. If the dietary intake of calcium is not sufficient to meet the obligatory requirements of the body, calcium is resorbed from the skeletal stores.

The body's reservoir for calcium and phosphorus is the trabeculae of the bone. If the food supply is abundant in calcium, the trabeculae will be well developed, but if consistently low in calcium content, the trabeculae may be practically absent.[9,24,35,36]

Resorption of Bone

Resorption is defined as "the loss of substance through physiologic or pathologic means; such as, loss of dentin and cementum of a tooth or of the alveolar process of the mandible or maxilla".[37]

Resorption of bone, like apposition, is a continuous process. It is only when demineralization exceeds formation that bone loss occurs. The exact mechanism for resorption is not completely known.

Concepts applicable to bone resorption include osteoclasia, osteolysis, and bone flow. Osteoclasia is a surface resorption brought about by osteoclasts;[25,38] osteolysis indicates a deep seated resorption of bone centered around the activity of mature osteocytes of the matrix;[10] and bone flow is an apparent replacement stream of bone tissue from the site of apposition toward the area of osteolysis.[10,25,39,40]

Pathologic manifestations of bone resorption include generalized osteoporosis, loss of alveolar bone in periodontal disease, and the reduction of residual ridges after the extraction of teeth.

Atwood[3] had noted that the total amount of bone loss and the rate of residual ridge resorption varied among individuals. He had also noted that the rate of resorption for a given patient varied at different times. In seeking causes of such variations,[3] he first organized the clinical factors into four major categories: (1) Anatomic: the quality of bone: (2) Metabolic: the effect of diet, hormones and the status of general health: (3) Functional: the effect of the frequency, intensity, duration and direction of force: (4) Prosthetic: the technical details involved in the use of dentures. Later, Atwood[41] combined the functional and prosthetic factors under the caption of 'mechanical'.

Garn[42] expressed similar views when he described osteoporotic bone loss, in general, as a nutritional problem, and endocrine problem, a bone problem, and an individual problem. According to Garn, alveolar bone loss that leads to diminution of tooth support, fenestration of the roots, and actual loss of teeth, is part of the osteoporotic process.[42]

Fenton[5] noted that research in bone resorption and its mechanisms encompass four areas: (1) the regulation of calcium homeostasis in the body by a reciprocal relationship between calcium concentrations and bone resorption; (2) the integrity of the skeleton as a structural unit which is thought to be controlled by opposing actions of parathyroid hormone and thyrocalcitonin; (3) the treatment of metabolic diseases that alter the concentration of serum calcium and phosphate; (4) the understanding of localized resorption and becoming aware of the mechanical stimulus that causes changes in bone structure surface contour.

Osteoporosis

Osteoporosis is defined as the condition which results in a loss of bone substance without a fundamental change in bone composition.[9,43,44] The early stages of this disorder are not readily recognized by roentgenography because at least 25 percent of bone mineral must be lost before changes are visible with this technique.

Osteoporosis had once been thought to be a disorder of the bone matrix and related to protein metabolism.[45,46] In more recent years, osteoporosis has been associated with disturbed calcium homeostasis.[11,31,3,47-58]

Nordin has suggested that osteoporosis might be due to prolonged negative calcium balance.[48,56] From his metabolic studies on seventeen patients with spinal and mixed osteoporosis, he found that the patients went into strongly sustained positive balance when given calcium supplements. He learned that these subjects had a higher than normal calcium requirement mainly because of their inability to vary their urine calcium with variations in their dietary intake.[48]

In 1965, Heaney[50] proposed "that the forces controlling the calcium ion concentration in the extracellular fluid comprised the basic elements of the mechanism underlying most of the osteoporoses." In 1969, he elaborated on the role both parathyroid hormone and calcitonin play on bone resorption and the mechanisms that lead to negative calcium balance. Heaney also thought that estrogen suppresses bone resorption by shifting the PTH dose response curve in the direction of decreased sensitivity, and that the withdrawal of estrogen allows the reverse shift which leads to accelerated skeletal loss.

Hossain and others[59] had suggested that excessive or unbalanced action of parathyroid hormone may be responsible for senile osteoporosis. In conjunction with this assumption, Berlyne[60] compared a group of 18-19 year olds with a group 65 and over for parathyroid activity and found the level of PTH significantly higher in the old. His findings indicate that PTH activity at the site of the kidney increases with age.

In an investigation of mandibles and radii of postmortem osteoporotic patients, Henrikson and Wallenius[57] had observed that the specific gravity of mineral content fell significantly with increasing age.

In their studies on animals, Anderson,[61] Draper[26] and others had noted that the calcium and phosphorus contents of femurs, lumbar vertebrae, and mandibles were more significantly reduced in the animals fed 1.2 and 1.8 percent phosphorus as compared to those fed 0.6 and 0.3 percent. All animals had been given diets of 0.6 percent calcium content.

From radiographic and histologic examination of necropsy material from four human subjects with periodontal disease and osteoporosis, Krook et al.[10] found that, within the human skeleton, bone loss occurs in the following decreasing order: the jaw bones, the ribs, the vertebrae, and the long bones.

Resorption of Alveolar Bone

Dentists have long speculated over the cause of the loss of alveolar bone. Both external and systemic factors have been suspected.

According to Glickman,[62] "A loss of alveolar bone occurs regardless of the condition of the gingival tissues or of the prosthetic appliance." He contends that the alveolar bone participates in the maintenance of the body calcium balance.[36]

Sobolik[1] considered aging as the most constant factor of bone loss because of the osteoblasts and the osteoclasts are the participating cells in the dynamic equilibrium of bone.

Massler[53] reported that the degenerated oral condition is often rampant during the female menopause. He also noted, in his investigation of residual ridge resorption in the elderly, that calcium deficiencies and negative calcium balance produce osteoporosis of the maxillae and the mandibles.

Reifenstein[63] related the reduction of anabolic hormones in postmenopausal women with accelerated bone resorption.

Page and Abrams associate the health of oral tissues with proper endocrine levels and proper calcium-phosphorus blood levels.[64]

Baylink and colleagues[13] stress parathyroid hormone as one of the most important systemic factors influencing resorption of alveolar bone.

Ortman[4] discusses many factors involved in the resorption of residual ridges, including endocrine dysfunction, nutritional deficiencies, stress, and alimentary failure. He also states that a rapid and abnormal loss in the residual ridges is indicative of general skeletal osteoporosis.

Atwood and Coy(65) had found that the anterior loss in the mandible was four times greater than in the maxilla.

Becks and Weber(47) were the first to disclose a relationship between the alveolar process and the general osseous system. In their nutritional experiments on dogs, they induced osteoporosis and rickets by varying the amount of calcium salts in the diets with and without vitamin D. As the control group for the low calcium salt mixture had died, their data was incomplete. From the animals that lived throughout the experiment, they were able to realize that the most extensive change that developed was in the bony part of the paradentium.

Since Beck and Weber's experiments in 1931, many experiments and investigations have been conducted in relation to the loss of alveolar bone.

In examining this vast work, one detects a definite interrelationship amongst the dietary intake of calcium and phosphorus; the function of the parathyroid glands; and the loss of alveolar bone as observed in periodontal disease, in edentulous jaws, and osteoporosis.

Krook and his associates(10) at New York State Vetinary College introduced the term nutritional secondary hyperparathyroidism to describe the resorption of bone that is caused by dietary calcium deficiency and/or phosphorus excess.

A low calcium intake results in hypocalcemia which serves as a stimulus for the secondary parathyroid hyperactivity. An optimal calcium intake with excess phosphorus produces a primary hyperphosphatemia and a secondary hypocalcemia.[25] This inverse relationship between Ca^{++} and $HPO_4^{=}$ occurs in a saturated blood serum. It is only when the saturation point is reached that a further increase of one ion will depress the other[25] by formation of insoluble $Ca_3(PO_4)_2$ or by excretion.[16]

A deficiency or depletion of dietary phosphorus results in hypophosphatemia and subsequent hypercalcemia caused by dissolution of bone that the concentration of serum calcium might remain within normal range.

A prolonged or excessive intake of nonabsorbable antacids can cause phosphorus depletion in man by the precipitation of insoluble phosphate.[66]

Formation of $HPO_4^{=}$ to buffer the acid load imposed by an 'acid ash' diet in man also removes $PO_4^{\equiv}$ from the serum. This theory was hypothesized by Wachman and Berstein[44] and tested by Ellis, Schura and Ellis[67] in a comparison study of vegetarians and omivores. The serum calcium was significantly lower (still in normal range) in the vegetarians.[67]

In studies with animals,[25,47,68] in which nutritional secondary hyperparathyroidism was either spontaneous or induced, it has been shown that the outstanding morphological feature of this disease is resorption of alveolar bone, especially the 'laminae dentes'; and the chief clinical manifestation is the detachment of teeth.

From the above criteria, Henrikson[25] concluded that periodontal disease is an early manifestation of nutritional secondary hyperparathyroidism in animals.

In man, the detachment of teeth is also a clinical manifestation of periodontal disease. WHO's expert committee,[69] 1961 considered gingivitis and calculus formation the "most common direct causes of periodontal disease" , but Glickman[36] contended that the "crux of the problem" of periodontal disease is in the alveolar bone.

Krook and others[11] found the lesions in alveolar bone in human periodontal disease qualitatively the same as those of experimental disease induced in animals by low dietary calcium. They treated ten subjects with 1 g of calcium for 180 days. They found enough improvement in the clinical factors and in the osseous structures of the alveolar process to conclude that the results support the view that excessive resorption of alveolar bone in periodontal disease is caused by dietary calcium deficiency.[11,12]

Krook and colleagues[10] continued their investigation with necropsy material from four human subjects with periodontal disease and osteoporosis. From radiographic and histological examination, they found that periodontal disease in man appears to be a manifestation of generalized osteoporosis. They suggest that the calcium-to-phosphorus imbalance in the average American diet induces nutritional secondary hyperparathyroidism which causes bone resorption in excess of bone formation.

From the preceding literature review, it seems most likely that disturbed calcium homeostasis contributes to the loss of alveolar bone in periodontal disease and in the residual ridge resorption; and that the resorption in both instances is an early manifestation of generalized osteoporosis.

Hegsted[70] has stated, "We do not even know what calcium deficiency looks like in man."

Perhaps, the loss of alveolar bone is a major symptom of calcium deficiency, as well as, calcium-phosphorus imbalance.

The purpose of this study was to repeat the study of Wical and Swoope[14] with a larger number of totally edentulous subjects in order to establish further and to document the correlation between dietary clacium and phosphorus and the degree of residual ridge resorption.

METHODS OF INVESTIGATION

In this study the diets of edentulous subjects with minimal resorption of the lower jaw bones were compared with diets of subjects with severe resorption.

Selection of Subjects

55 subjects who had been totally edentulous for at least three years participated in the investigation. All were patients from the dental clinic or faculty practice offices of Loma Linda University School of Dentistry. They were selected on the bases of their interest in their denture problems and their willingness to provide a written record of their dietary intake.

Classification of Subjects

The 55 subjects were divided into two groups according to the degree of resorption as revealed in their radiographs.

Group I: Group with minimal resorption

The 22 subjects whose radiograph indicated a loss of mandibular height equal to or less than 1/3.

Group II: Group with severe resorption

The 33 subjects whose radiograph indicated a loss of greater than 1/2.

Those subjects whose ridge showed a loss greater than 1/3 but less than 1/2 were not used in the study because of the possibility of error in categorizing them.

Method of Measurement

Using the patient's panoramic radiograph of the jaws, the amount of reduction of residual ridge height of the mandible was estimated by measuring the height of the remaining bone and comparing it to the distance from the inferior border of the mandible to the lower edge of the mental foramen according to the method of Dr. Wical and Swoope.[71] The height of a normal non-resorbed mandible is approximately 3 times the distance between the inferior border of the mandible and the mental foramen.

Diet Surveys and Analyses

Pertinent information of dietary habits and dental problems were recorded during the initial interview. Each subject was given a preprinted booklet in which he (she) kept a seven day meal record according to oral and written instructions. When the record was returned, it was reviewed in the presence of the subject in order to insure completeness and accuracy.

The information on the diet records was transferred to work sheets, whereon the name of the food item, a code number,[72] the amount,[73] and whether meat or non-meat protein were indicated. The data for each food item on the work sheets was transferred to a computer card. All cards were then computerized for a program of the composition of foods as depicted in the U. S. Dept. of Agriculture Handbook No. 8.[72]

Statistical analysis was determined on the association between sex and resorption; sex and age; age and resorption, and on the data of the average daily intake of calcium, phosphorus, the calcium-to-phosphorus ratio, and a combination of calcium intake, the calcium-to-phosphorus ratio, and the degree of residual ridge resorption.

RESULTS

Table I shows a comparison by age and denture-wearing experience of the group with minimal resorption with that of the group with severe resorption. The difference difference between the means, in both instances, was very slight. For Group I, the average age was 61.9 years and the average number of years of denture-wearing experience was 21.1; for Group II, the means were 62.3 years for age, and 20.8 years for denture experience. Figure 1 gives the distribution of all subjects according to age.

Contingency tables (Tables II, III, and IV) were set up to test for association between the degree of resorption and sex, resorption and age, and sex and age. The association between sex and resorption proved significant ($p < .01$) with 70 percent of the women but only 40 percent of the men suffering severe bone loss. The association between resorption and age and between sex and age was not significant except that the tests between resorption and age showed a slight increase with increasing age while those between sex and age showed a slight decrease.

The individual values for the average daily intake of all nutrients covered a wide range of values with much overlapping between the two groups. Statistical analysis, comparing Group I with Group II, found a significant difference between the means of the average daily intakes of calcium and of phosphorus but only a slight difference between the means of the calcium-to-phosphorus ratios. Data is summarized in Table V.

Table I. Comparison of the two study groups according to sex, age, and denture-wearing experience.

Group	No. of subjects	Sex		Patient age (yrs.)			Denture experience (yrs.)		
		Male	Female	Mean	Range	S.D.	Mean	Range	S.D.
Minimal resorption	22	15	7	61.86	42-80	11.9	21.1	4-40	9.5
Severe resorption	33	10	23	62.33	33-78	10.9	20.8	6-42	10.7
t value				0.13†			0.12†		
$t_{0.975}$, 5% level of significance				2.01			2.01		
p				$0.80 < p < 1.0$			$0.80 < p < 1.0$		

† Difference is not significant.

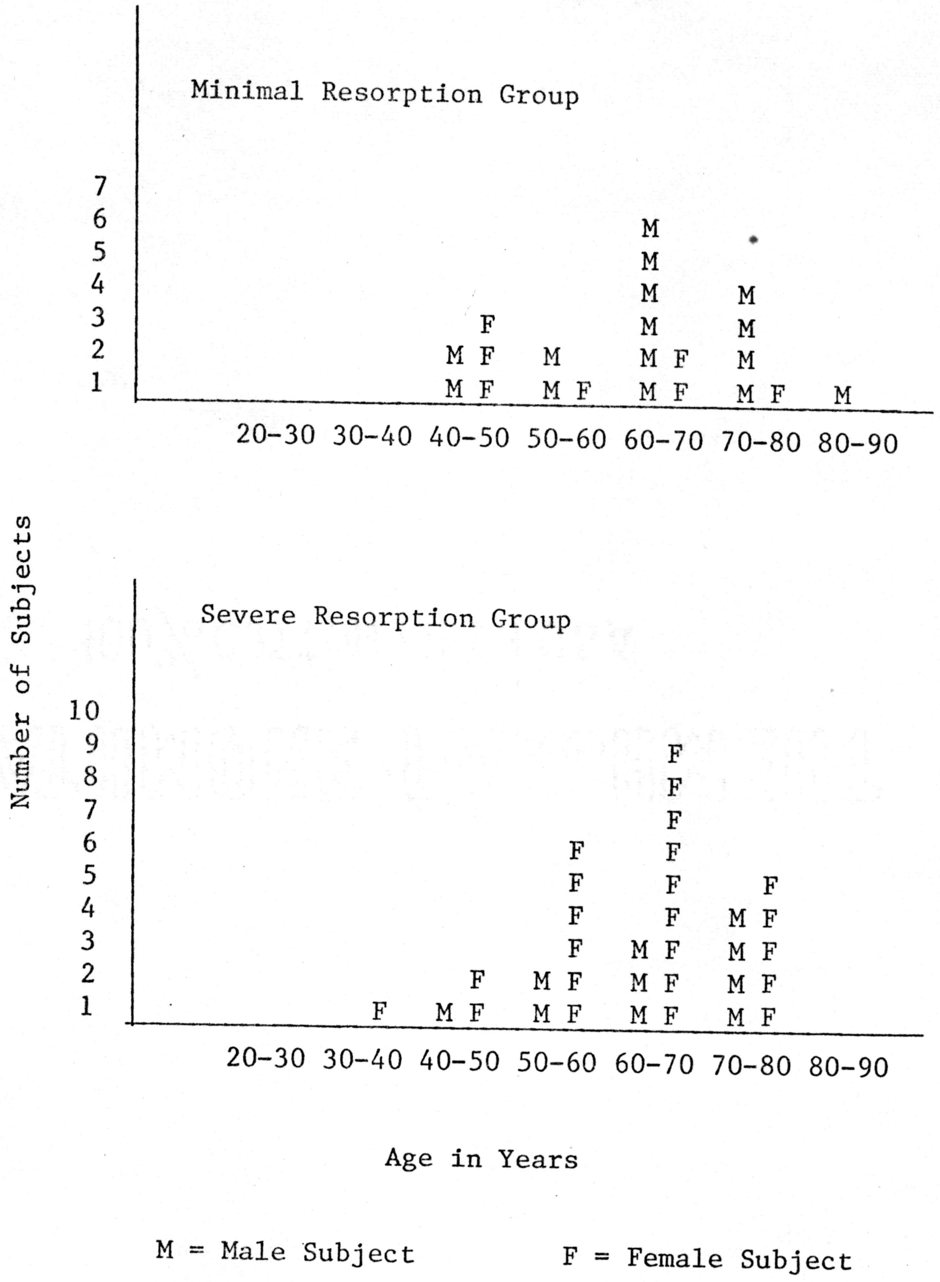

Fig. 1. Distribution of 55 Edentulous Subjects According to Age.

Table II. Contingency tables: test for association between the degree of resorption and sex.

		Column 1 Males	Column 2 Females
Row 1:	Minimal Resorption	15	7
Row 2:	Severe Resorption	10	23
Chi^2 =			7.64 *
p		$0.005 < p < 0.01$	

* There is an association between the row and the column classifications.

Table III. Contingency tables: test for association between the degree of resorption and age.

		Column 1	Column 2	Column 1	Column 2
		< 55	≥ 55	< 65	≥ 65
Row 1:	Minimal Resorption	7	15	9	13
Row 2:	Severe Resorption	9	24	17	16
Chi^2 =			0.131 †		0.596 †
p		$0.7 < p < 0.8$		$0.4 < p < 0.5$	

† There is no association between the row and the column classifications.

Note: Association between resorption and age increases slightly with increasing age.

Table IV. Contingency tables: test for association between sex and age.

	Column 1 < 55	Column 2 $\geq$ 55	Column 1 < 65	Column 2 $\geq$ 65
Row 1: Males	5	20	10	15
Row 2: Females	11	19	16	14
Chi^2 =		1.832 †		0.973 †
p	$0.10 < p < 0.2$		$0.3 < p < 0.4$	

† There is no association between the row and the column classifications.

Note: Association between sex and age decreases slightly with increasing age.

Table V. Comparison of the average daily intake of calcium and phosphorus and the dietary calcium-to-phosphorus ratio.

Group	Calcium (mg)			Phosphorus (mg)			Ca/P Ratio		
	Mean	Range	S.D.	Mean	Range	S.D.	Mean	Range	S.D.
Minimal resorption 15 men 7 women	759	377-1153	229	1254	712-1757	227	.605	.347-.937	.155
Severe resorption 10 men 23 women	591	322-	174	1024	632-1670	236	.582	.353-.997	.140
t value	2.91 *			3.62 *			0.575 †		
$t_{0.975}$, 5% level of significance	2.005			2.005			2.005		
p	$0.001 < p < 0.01$			$p < 0.01$			$0.4 < p < 0.6$		

* Difference is significant. † Difference is not significant.

The greatest significant difference was noted in comparing the two groups according to both their intakes of calcium and their calcium-to-phosphorus ratios. Tests for association between calcium intake and resorption; Ca/P ratio and resorption; and calcium intake, together with Ca/P ratio and resorption appear in Tables VI-VIII.

Calcium

The mean values for the average daily intake of calcium were 758 mg for the group with minimal resorption and 591 mg for those with severe resorption. The mean value for the entire group was 658 mg as compared to the median value of 641 mg. All of these values were less than the United States Recommended Daily Allowance of 800 mg.[20] Of the first group, 45 percent exceeded the minimum RDA; 68 percent, the mean; and 73 percent, the median. Of the second group, 9 percent were above the RDA; 30 percent, the mean; and 33 percent, the median. The distribution of dietary calcium intakes is shown in Figure 2.

Phosphorus

Of the group with little bone loss, none of the men and only one of the women had an average daily intake of phosphorus less than the minimum RDA of 800 mg, while 1 man and 2 women had less than the mean of 1116 mg, and 1 man and 2 women had less than the median of 1143 mg. Of the group with greater bone loss, 1 man and 4 women had intakes less than 800 mg; 5 men and 17 women, less than the mean of 1116 mg; and 5 men and 19 women, less than the median value of 1143 mg. Dis-

Table VI. Contingency Table: test for association between the degree of resorption and the average daily intake of calcium.

	Column 1 Calcium > 641 mg	Column 2 Calcium ≤ 641 mg
Row 1: Minimal Resorption	16	6
Row 2: Severe Resorption	11	22
χ^2 =		8.196 *
p	$0.0005 < p < 0.005$	

* There is association.

****

Table VII. Contingency Table: test for association between the degree of resorption and the calcium/phosphorus ratio.

	Column 1 Ca/P > .570	Column 2 Ca/P ≤ .570
Row 1: Minimal Resorption	11	11
Row 2: Severe Resorption	16	17
χ^2 =		0.0122 †
p	$0.9 < p < 0.95$	

† There is no association.

Table VIII. Contingency Table: test for association among the Ca/P ratios (row), the average daily intakes of calcium (column) and the degree of resorption (block).

Block 1: Minimal Resorption

		Column 1	Column 2
		Calcium > 641 mg	Calcium ≤ 641 mg
Row 1:	Ca/P Ratio > .570	11	0
[illegible]	[illegible]	5	6

Block 2: Severe Resorption

		Column 1	Column 2
		Calcium > 641 mg	Calcium ≤ 641 mg
Row 1:	Ca/P Ratio > .570	6	9
Row 2:	Ca/P Ratio ≤ .570	5	13

χ^2 = 16.171 *

p < 0.0005

* There is association.

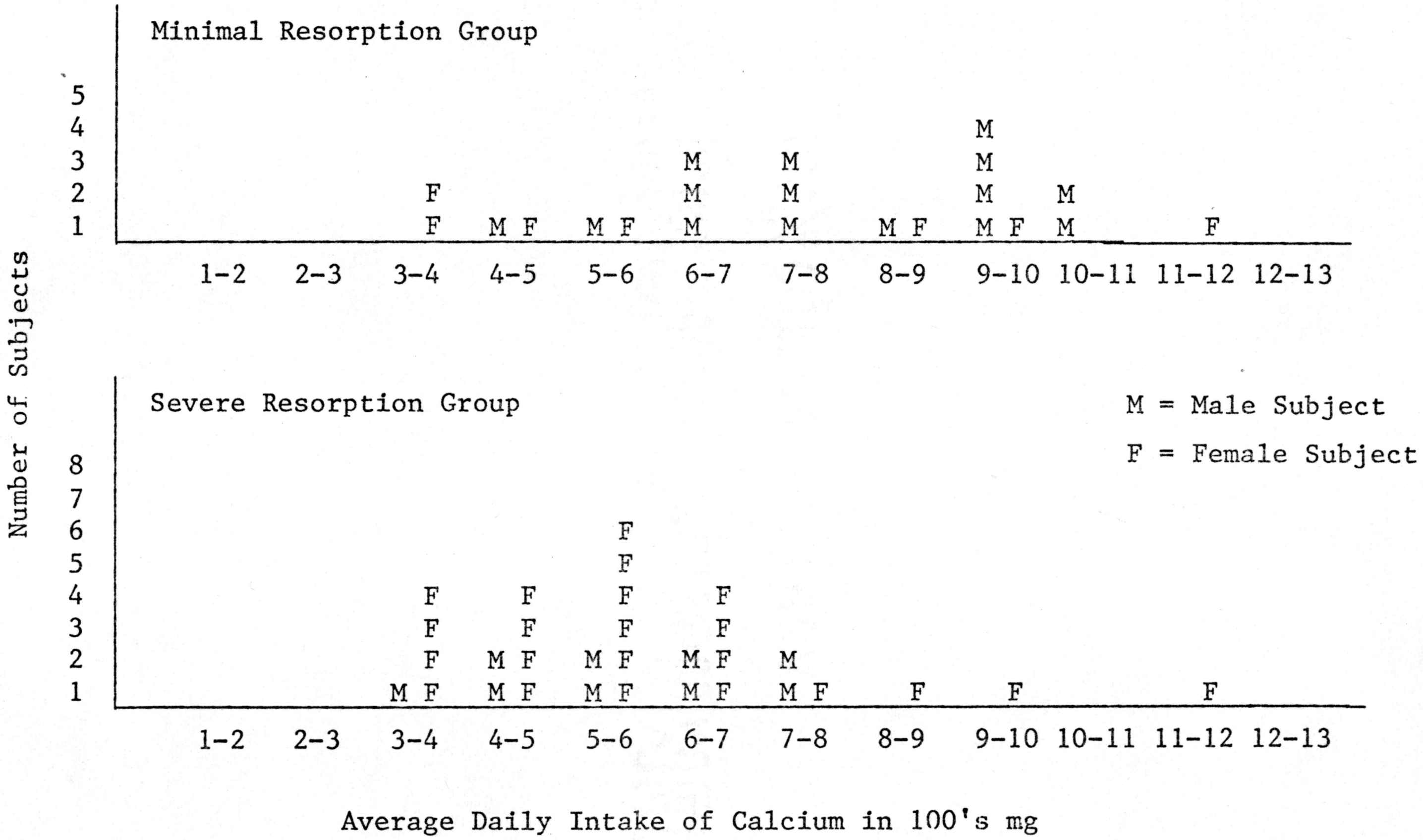

Figure 2. Distribution of the average daily intakes of calcium by 55 edentulous subjects.

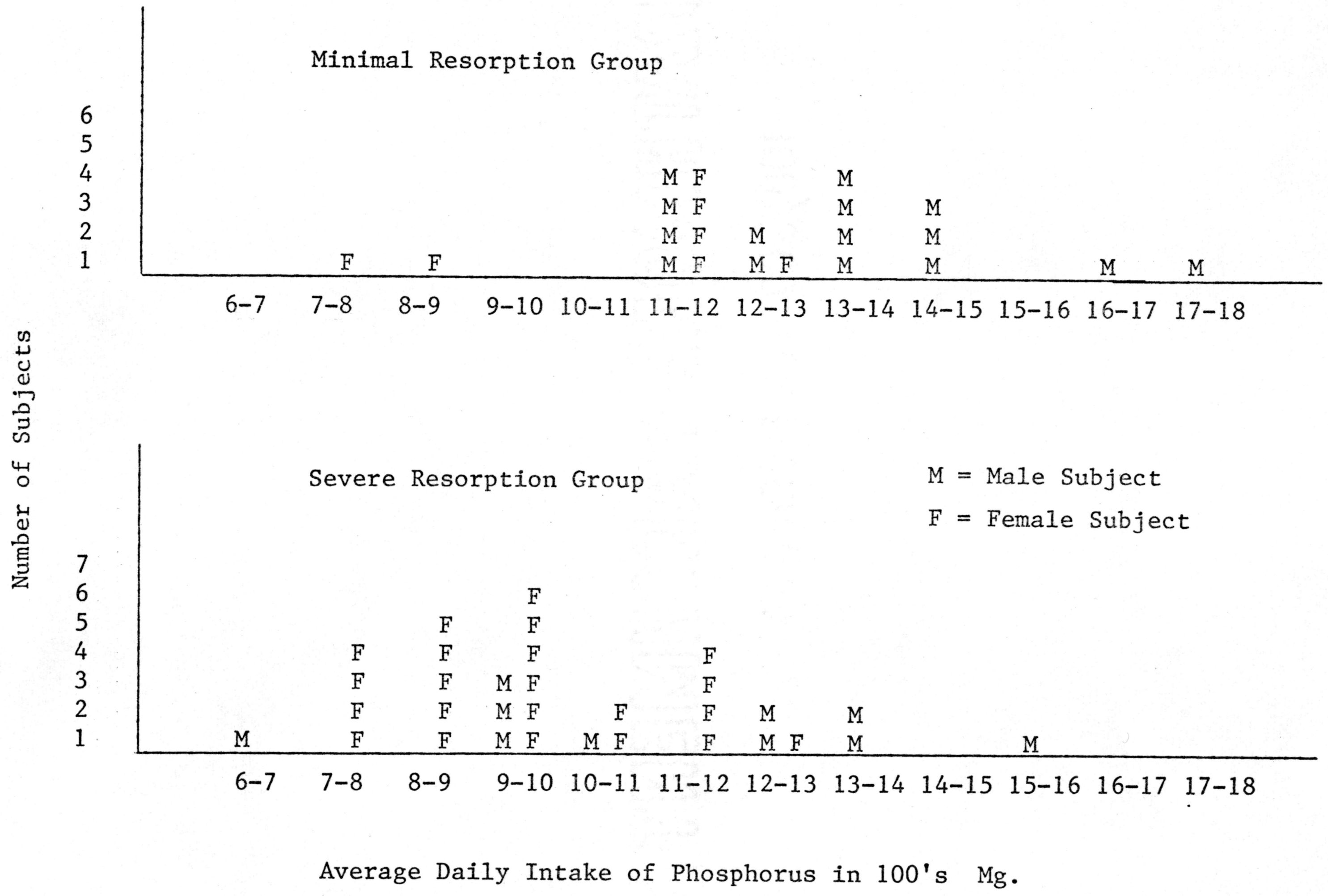

Fig. 3. Distribution of the average daily intakes of phosphorus of 55 edentulous subjects.

tribution of dietary phosphorus is illustrated in Figure 3.

Calcium-to-Phosphorus Ratio (Ca/P)

The RDA of 800 mg for both calcium and phosphorus gives a Ca/P ratio of 1/1. Only one subject, a woman in Group II had a ratio this low. Within the acceptable range of .667-1.0, there were 4 men and 3 women from the first group (32 percent) and 6 women from the second (18 percent). The mean value was 0.591 and the median, 0.570; both of which are less than the minimum RDA of 0.667. Of those with minimal resorption, 7 men and 3 women (45 percent) exceeded the mean while 8 men and 3 women (50 percent) were above the median. Of those with severe resorption, 1 man and 8 women (27 percent) were in excess of the mean, but 2 men and 14 women (48 percent) exceeded the median. Distribution of calcium-to-phosphorus ratios is depicted in Figure 4.

In testing for association among the three variables of dietary calcium intake, the calcium-to-phosphorus ratio, and the degree of residual ridge resorption, three sets of criteria were used: (1) the median values of 641 mg calcium and 0.570 Ca/P ratio; (2) the mean values of 658 mg calcium and 0.591 Ca/P ratio; and (3) the RDA of 800 mg calcium and the acceptable range of 0.667-1.0 for the Ca/P ratio. (Appendix 57-59)

Statistically speaking, only the test with the median values had goodness of fit, wherein, no more than 20 percent of the expected values were less than 5. In the test using the mean values, the significant values of individual statistics indicate a positive correlation between high calcium intake (>658 mg) and high Ca/P ratio

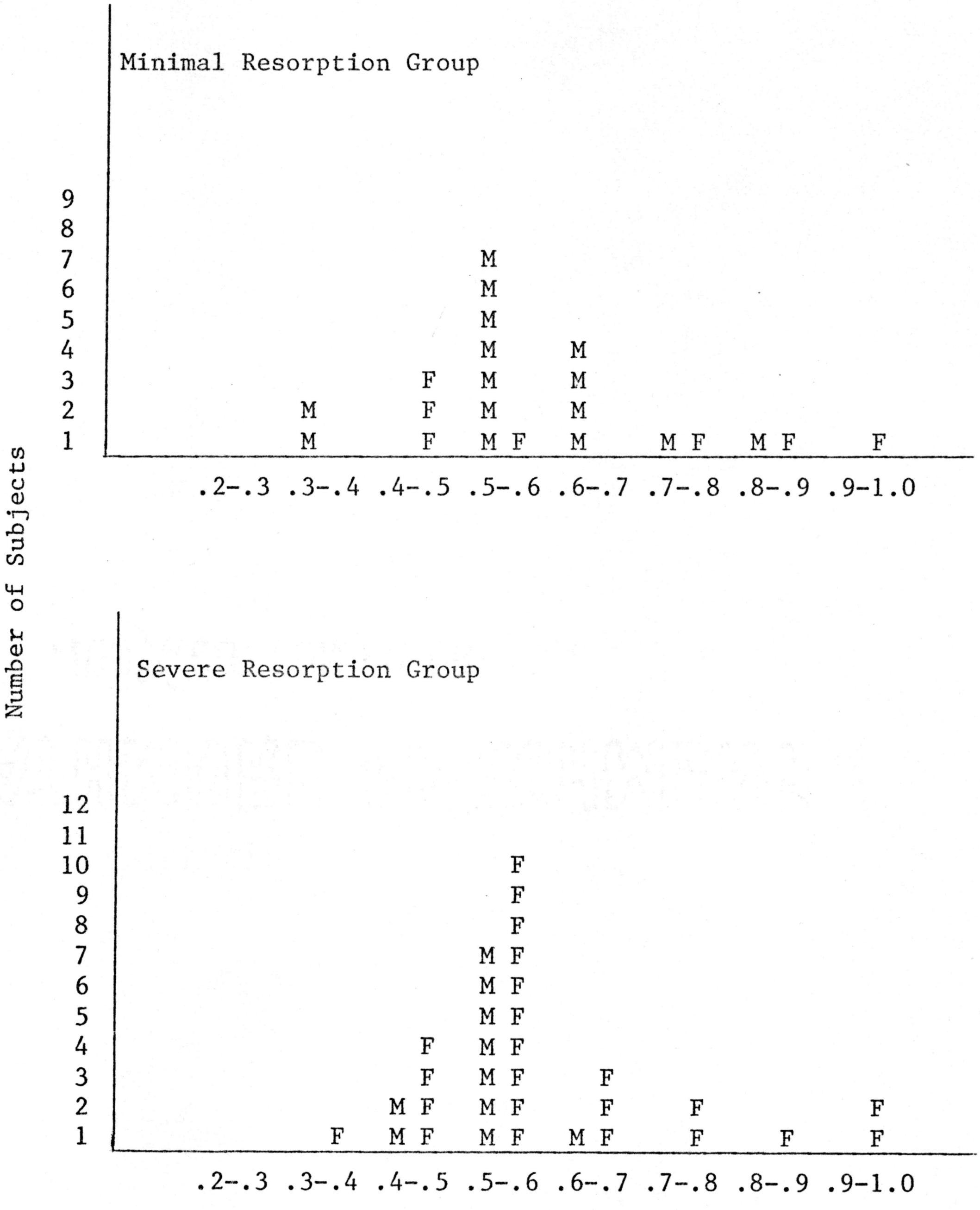

Fig. 4. Distribution of the dietary calcium/phosphorus ratios of 55 edentulous subjects.

(>0.591) and minimal resorption, as well as, between low calcium intake ($\leq$658 mg), low Ca/P ratio ($\leq$0.591) and severe resorption. In the test using the minimum RDA of 800 mg calcium and 0.667 Ca/P ratio, the individual statistic for the cell representing those from Group I with high intake of calcium and high Ca/P ratio suggests that these values may not be readily attained simultaneously by a general population.

The group with minimal resorption showed better quality diets than the group with severe resorption. However, only one subject, a woman from Group II, met the RDA for all the nutrients analysed. The nutrients most frequently less than the minimum recommended daily allowance in both groups were calcium, calcium-to-phosphorus ratio, fiber, thiamine, vitamin A, riboflavin and niacin. The low intake of foods containing niacin, however, was offset by the niacin equivalents from an adequate intake of protein. Diets are evaluated in Table IX.

Table IX. Evaluation of diets in terms of nutrients less than the minimum RDA.

Nutrient	RDA	% Gp. I < RDA	% Gp. II < RDA	% of all subjects < RDA
Calcium	800.0 mg	54.5 %	90.9 %	76.4 %
Phosphorus	800.0 mg	4.5 %	15.1 %	10.9 %
Ca/P Ratio	0.667-1.0	68.2 %	78.8 %	74.5 %
Iron	10.0 mg	9.1 %	30.3 %	21.8 %
Vitamin A	men 5000.0 I.U. women 4000.0 I.U.	45.4 %	39.4 %	41.2 %
Thiamine	men 1.2 mg women 1.0 mg	50.0 %	69.7 %	61.8 %
Riboflavin	men 1.5 mg women 1.1 mg	22.7 %	39.4 %	32.7 %
Ascorbic Acid	45.0 mg	13.6 %	9.1 %	10.9 %

DISCUSSION

The significant correlation between dietary calcium intake and calcium-to-phosphorus ratio and degree of residual ridge resorption that was found in this investigation supports the view that oral bone loss in humans is mediated by calcium insufficiency or excess phosphorus and that the problem is compounded if both conditions exist simultaneously. These findings also suggest that the loss of alveolar bone is a manifestation of osteoporosis, since disturbed calcium homeostasis is believed to occur in most cases of human osteoporosis,[50,57] and the site of predilection for resorption is the gnathic bones.[10]

Dietary phosphorus can disturb calcium homeostasis if either inadequate or excessive. Bone is resorbed in each instance in order that the concentration of serum calcium be maintained within normal range. While phosphorus deficiency is not common in the United States, an adequate intake of phosphorus can be rendered ineffective by excessive precipitation of insoluble phosphates, as in the use of nonabsorbable antacids[66]; and/or the formation of complex ions like $HPO_4^{=}$ as a buffer mechanism.

Ellis, Schura, and Ellis,[67] in their study comparing bone density of omnivores, concluded that the slight elevation of serum calcium in omnivores was caused by the removal of phosphate ions to buffer acid ash.

The prevalence of phosphorus in foods commonly used in the

United States' diets makes an excess of dietary phosphorus in proportion to calcium intake, a frequent occurrence; especially if the intake of food products from the basic milk group are less than 2 servings daily per adult.

Davidson and Passmore[74] estimate the average daily intake of phosphorus in the American diet to be 1.5 g. Henrikson[25] had speculated that the average diet in the United States contains approximately 2.8 times the amount of phosphorus as calcium. In this study, the average daily intakes of phosphorus ranged from 632 - 1757 mg with a mean intake of 1116 mg which was 1.69 times as much phosphorus as calcium. The overall mean intake of calcium was 658 mg and the overall mean for the Ca/P ratio was 0.591. These values for phosphorus and the Ca/P ratio are less than those of the above mentioned investigators but greater than the minimum RDA of 800 mg phosphorus and a ratio of P/Ca of 1/1.

The most significant correlation of this investigation was noted in the contingency tests for association among the three variables of average daily calcium intake, the Ca/P ratio, and the degree of residual ridge resorption. Using the overall mean values of 658 mg calcium and 0.591 Ca/P ratio, statistical analysis demonstrated a highly significant and positive correlation ($p < .0005$) between a combination of high calcium intake (> 658 mg) and high Ca/P ratio (>.591) and minimal resorption, as well as, a positive and highly significant correlation ($p < .0005$) between a combination of low calcium intake (< 658 mg) and low Ca/P ration ($\leq$ .591) and severe resorption.

These results confirm Jowsey's[28] supposition that the proportion of calcium to phosphorus in the diet is a more important factor of bone loss than the absolute intake of either mineral.

Further statistical analysis compared sex with resorption; sex with age; and age with resorption. There was a significant associa- between the variables of sex and resorption ($p < .01$) but none between sex and age nor age and resorption.

These results agree with the observation that oral bone loss is more prevalent among women than men; but disagree with the assumption that resorption of residual ridges is a "normal" part of aging. It is possible, however, that the sex distribution of patients who participated in this study was merely coincidence.

It is also possible that some of the characteristics attributed to aging are actually pathologic changes due to dietary deficiencies. In this study, only one subject met the minimum recommended daily allowance for all the nutrients analysed. Although subjects in both groups were low in one or more nutrients, the individuals with severe bone loss had the greater number less than the RDA. The men of this group had the poorest quality diets of all.

In decreasing order of occurrence, the nutrient intakes that were less than the minimum RDA for both groups were: calcium, calcium-to-phosphorus ratios, thiamine, fiber, vitamin A, iron, riboflavin, phosphorus and ascorbic acid.

The above nutrition pattern coincides with the report that since

1949, the consumption of foods within the United States shows a decline in the availability of calcium, magnesium, thiamine, riboflavin, Vitamin A and Vitamin C.[75,76,77]

Perhaps the problem of residual ridge resorption could be alleviated, if not prevented, through (1) motivation and education of dental patients to improve their dietary habits; and (2) calcium supplementation for those whose dietary intakes of calcium are inadequate and their phosphorus intake is excessive of a 1/1 ratio with calcium.

Areas for future research might include further investigation of the role of phosphorus in the relation to the homeostatic equilibrium of calcium, as well as the quality of the total diet.

Steinman and Leonora[78] had observed, in their work on rats, that the dissolution of teeth, as noted in the incidence of caries, was increased as the quality of the diet was decreased by the removal of nutrients.

As teeth and bone have similar chemical composition, the importance of the total quality of the diet in relation to the problem of residual ridge resorption should not be overlooked.

SUMMARY

This investigation was a continuation of that of Wical and Swoope of the relationship between dietary calcium and phosphorus and the resorption of alveolar bone in edentulous subjects.

Seven-day diets of 22 subjects with minimal loss of bone were compared with seven-day diets of 33 subjects with severe loss. The ages of both groups were comparable with the range from 33 to 80 years for all subjects; as were the years of denture experience with the range from 4-40 years.

The individual intakes covered such a wide range with much overlapping of values between the two groups. Statistical analysis showed a significant correlation between the average daily intakes of calcium ($p < .001$) and of phosphorus ($p < .001$) and the degree of residual ridge resorption. Although there was no significant correlation between loss of bone and calcium-to-phosphorus ration, there was a highly significant association ($p < .0005$) when both the intake of calcium and the calcium-to-phosphorus ratio were compared with the degree of resorption.

The results of the statistical analysis indicate four important things: (1) the RDA of 800 mg of calcium may not be readily attained by a general population in their daily diet; (2) an intake of calcium less than 800 mg and an intake of phosphorus in excess of 1.5 times that of a low intake of calcium mediates resorption of alveolar bone; (3) that loss of alveolar bone seems more prevalent in women then in

men and (4) reduction of residual ridges is not necessarily a "normal" part of aging.

98 percent of the subjects failed to meet the minimum RDA for all of the nutrients analysed. The nutrients which subjects were most often low in were calcium, calcium-to-phosphorus ratio, fiber, vitamin A, thiamine, and riboflavin.

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APPENDIX

STATISTICAL TESTS FOR ASSOCIATION IN CONTINGENCY TABLES

Test for Two Variables

Hypothesis: There is no association between the row and column classifications.

Degrees of freedom (d.f.) = (r-1)(c-1)

$$E_{ij} = N \frac{R_i}{N} \frac{C_j}{N} \qquad T = \Sigma_{ij} \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \qquad \chi^2 = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{O_{ij}^2}{E_{ij}} - n$$

****

Test for Three Variables

Hypothesis: There is no association among the row, column and block classifications.

Degrees of freedom (d.f.) = (r-1)(c-1)(b-1)

$$E_{ijk} = N \frac{R_i}{N} \frac{C_j}{N} \frac{B_k}{N} \qquad T = \Sigma_{ijk} \frac{(O_{ijk} - E_{ijk})^2}{E_{ijk}}$$

$$\chi^2 = \sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{b} \frac{O_{ijk}^2}{E_{ijk}} - n$$

****

Accept hypothesis: Test value $\leq$ critical value

Reject hypothesis: Test value > critical value

Critical value: $\chi^2_{0.95} = 3.84$ for 1 d.f.

O = Observed	E = Expected	T = Test Statistic
R = Row Total	C = Column Total	B = Block Total
r = row	c = column	b = block
n = number		N = Total Number

STATISTICAL TEST FOR ASSOCIATION IN CONTINGENCY TABLES

Resorption and Sex

Hypothesis: There is no association between the row classification of resorption and the column classification of sex.

Accept hypothesis:	Test value $\leq$ critical value
Reject hypothesis:	Test value > critical value
Critical value:	$\chi^2_{0.95} = 3.84$ for 1 d.f.
Row 1	Minimal Resorption
Row 2	Severe Resorption
Column 1	Males
Column 2	Females

	Row	Column	Observed	Expected	Statistic
	1	1	15	10	2.50
	1	2	7	12	2.08
	2	1	10	15	1.67
	2	2	23	18	1.39
$\chi^2 =$					7.64 *
p			$0.005 < p < 0.01$		

Result: Reject hypothesis. Test value exceeds critical value.

* = There is an association between the row and column classifications.

Note: Test has goodness of fit. None of the expected values are less than 5.

Statistical Test for Association in Contingency Tables

Resorption and Age 55

Hypothesis: There is no association between the row classification of residual ridge resorption and the column classification of age.

Accept hypothesis:	Test value $\leq$ critical value
Reject hypothesis:	Test value > critical value
Critical value	$Chi^2_{0.95} = 3.84$ for 1 d.f.
Row 1	Minimal Resorption Group
Row 2	Severe Resorption Group
Column 1	< Age 55
Column 2	$\geq$ Age 55

Row	Column	Observed	Expected	Statistic
1	1	7	6.4	0.056
1	2	15	15.6	0.023
2	1	9	9.6	0.037
2	2	24	23.4	0.015
Chi^2 =				0.131 ×

Result: Accept hypothesis. Test value is less than critical value.

× = There is no association between the row and the column classifications.

Note: Test has goodness of fit. None of the expected values are less than 5.

p $0.7 < p < 0.8$

Statistical Test for Association in Contingency Tables

Resorption and Age 65

Hypothesis: There is no association between the row classification of residual ridge resorption and the column classification of age.

Accept hypothesis:	Test value $\leq$ critical value
Reject hypothesis:	Test value > critical value
Critical value	$Chi^2_{0.95} = 3.84$ for 1 d.f.
Row 1	Minimal Resorption Group
Row 2	Severe Resorption Group
Column 1	< Age 65
Column 2	$\geq$ Age 65

	Row	Column	Observed	Expected	Statistic
	1	1	9	10.4	0.188
	1	2	13	11.6	0.169
	2	1	17	15.6	0.126
	2	2	16	17.4	0.113
Chi^2 =					0.596 ×

Result: Accept hypothesis. Test value is less than critical value.

× = There is no association between the row and the column classifications.

Note: Test has goodness of fit. None of the expected values are less than 5.

p $0.4 < p < 0.5$

Statistical Test for Association in Contingency Tables

Sex and Age 55

Hypothesis: There is no association between the row classification of sex and the column classification of age.

Accept hypothesis:	Test value $\leqq$ critical value
Reject hypothesis:	Test value > critical value
Critical value	$Chi^2_{0.95} = 3.84$ for 1 d.f.
Row 1	Males
Row 2	Females
Column 1	< Age 55
Column 2	$\geqq$ Age 55

	Row	Column	Observed	Expected	Statistic
	1	1	5	7.3	0.709
	1	2	20	17.7	0.291
	2	1	11	8.7	0.590
	2	2	19	21.3	0.242
Chi^2 =					1.832 ×

Result: Accept hypothesis. Test value is less than critical value.

× = There is no association between the row and the column classifications.

Note: Test has goodness of fit. None of the expected values are less than 5.

p $0.10 < p < 0.2$

STATISTICAL TEST FOR ASSOCIATION IN CONTINGENCY TABLES

Sex and Age 65

Hypothesis: There is no association between the row classification of sex and the column classification of age.

Accept hypothesis:	Test value $\leq$ critical value
Reject hypothesis:	Test value > critical value
Critical value	$\chi^2_{0.95} = 3.84$ for 1 d.f.
Row 1	Males
Row 2	Females
Column 1	< Age 65
Column 2	$\geq$ Age 65

	Row	Column	Observed	Expected	Statistic
	1	1	10	11.8	0.280
	1	2	15	13.2	0.251
	2	1	16	14.2	0.233
	2	2	14	15.8	0.209
χ^2 =					0.973 ×
p			$0.3 < p < 0.4$		

Result: Accept hypothesis. Test value is less than critical value.

× = There is no association between the row and column classifications.

Note: Test has goodness of fit. None of the expected values are less than 5.

Statistical Test for Association in Contingency Tables

Median Value of Calcium and Degree of Resorption

Hypothesis: There is no association between the row classification of residual ridge resorption and the column classification of the average daily intake of calcium.

Accept hypothesis:	Test value ≤ critical value
Reject hypothesis:	Test value > critical value
Critical value	$Chi^2_{0.95} = 3.84$ for 1 d.f.

Row 1	Minimal Resorption Group
Row 2	Severe Resorption Group
Column 1	> 641 mg Ca (median value)
Column 2	≤ 641 mg Ca

Row	Column	Observed	Expected	Statistic
1	1	16	10.8	2.504
1	2	6	11.2	2.414
2	1	11	16.2	1.669
2	2	22	16.8	1.609
Chi^2 =				8.196*

Result: Reject hypothesis. Test value exceeds critical value.

* There is an association between the row and column classifications.

Note: Test has goodness of fit. None of the expected values are less than 5.

p $0.0005 < p < 0.005$

Statistical Test for Association in Contingency Tables

Median Value of Ca/P Ratio and Degree of Resorption

Hypothesis: There is no association between the row classification of residual ridge resorption and the column classification of the average daily Ca/P ratio.

Accept hypothesis:	Test value $\leq$ critical value
Reject hypothesis	Test value > critical value
Critical value	$\text{Chi}^2_{0.95} = 3.84$ for 1 d.f.
Row 1	Minimal Resorption Group
Row 2	Severe Resorption Group
Column 1	> .570 (Ca/P, median value)
Column 2	$\leq$ .570

	Row	Column	Observed	Expected	Statistic
	1	1	11	10.8	0.004
	1	2	11	11.2	0.004
	2	1	16	16.2	0.002
	2	2	17	16.8	0.002
Chi^2 =					0.012 ×

Result: Accept hypothesis. Test value is less than critical value.

× = There is no association between the row and column classifications.

Note: Test has goodness of fit. None of the expected values are less than 5.

p $0.9 < p < 0.95$

STATISTICAL TEST FOR ASSOCIATION IN CONTINGENCY TABLES

Median Values of Calcium and Calcium-to-Phosphorus Ratio

and the Degree of Resorption

Hypothesis: There is no association among the row classification of the Ca/P ratio, the column classification of the average daily intake of calcium and the block classification of residual ridge resorption.

Accept hypothesis:	Test value $\leq$ critical value
Reject hypothesis:	Test value > critical value
Critical value	$\chi^2_{0.95} = 3.84$ for 1 d.f.
Row 1	> 0.570 (Ca/P, median value)
Row 2	$\leq$ 0.570 Ca/P Ratio
Column 1	> 641 mg Ca (median value)
Column 2	$\leq$ 641 mg Ca
Block 1	Minimal Resorption Group
Block 2	Severe Resorption Group

Row	Column	Block	Observed	Expected	Statistic
1	1	1	11	5.10	6.825
1	2	1	0	5.29	5.294
2	1	1	5	5.69	0.085
2	2	1	6	5.90	0.002
1	1	2	6	7.66	0.360
1	2	2	9	7.94	0.153
2	1	2	5	8.54	1.467
2	2	2	13	8.86	1.985
χ^2 =					16.171 *
p					< 0.0005

Result: Reject hypothesis. Test value exceeds critical value.

* = There is an association among the row, column and block classifications.

Note: Test has goodness of fit. None of the expected values are less than 5.

Statistical Test for Association in Contingency Tables

Mean Values of Calcium and Calcium-to-Phosphorus Ratio and the Degree of Resorption

Hypothesis: There is no association among the row classification of the Ca/P ratio, the column classification of the average daily calcium intake and the block classification of residual ridge resorption.

Accept hypothesis:	Test value $\leq$ critical value
Reject hypothesis:	Test value > critical value
Critical value	$Chi^2_{0.95}$ = critical value for 1 d.f.
Row 1	> 0.591(Ca/P ratio, mean value)
Row 2	$\leq$ 0.591 Ca/P ratio
Column 1	> 658 mg Ca (mean value)
Column 2	$\leq$ 658 mg Ca
Block 1	Minimal Resorption Group
Block 2	Severe Resorption Group

Row	Column	Block	Observed	Expected	Statistic
1	1	1	10	3.45	12.406
1	2	1	0	4.14	4.145
2	1	1	5	4.73	0.016
2	2	1	7	5.67	0.310
1	1	2	5	5.18	0.006
1	2	2	4	6.22	0.764
2	1	2	5	7.09	0.616
2	2	2	19	8.51	12.935
Chi^2 =					31.198 *
P				<	0.0005

Result: Reject hypothesis. Test value exceeds critical value.

* There is an association among the row, the column, and the block classifications.

Note: Test lacks goodness of fit. Over 20 percent of the expected values are less than 5.

STATISTICAL TEST FOR ASSOCIATION IN CONTINGENCY TABLES

Recommended Daily Allowances of Calcium
and Calcium-to-Phosphorus Ratio

Hypothesis: There is no association among the row classification of the Ca/P ratio, the column classification of the average daily intake of calcium and the block classification of residual ridge resorption.

Accept hypothesis:	Test value $\leq$ critical value
Reject hypothesis:	Test value > critical value
Critical value:	$\chi^2_{0.95} = 3.84$ for 1 d.f.
Row 1	.667 - 1.0 (RDA range for Ca/P ratio)
Row 2	< .667 Ca/P Ratio
Column 1	$\geq$ 800 mg Ca (RDA)
Column 2	< 800 mg Ca
Block 1	Minimal Resorption Group
Block 2	Severe Resorption Group

Row	Column	Block	Observed	Expected	Statistic
1	1	1	7	1.2	27.067
1	2	1	0	4.0	4.000
2	1	1	3	3.97	0.237
2	2	1	12	12.83	0.367
1	1	2	2	1.84	0.014
1	2	2	4	5.96	0.645
2	1	2	1	5.96	4.128
2	2	2	26	19.24	2.375
χ^2 =					38.833 *
p					< 0.0005

Result: Reject hypothesis. Test value exceeds critical value.

* = There is an association among the row, column and block classifications.

Note: Test lacks goodness of fit. Over 20 percent of the expected values are less than 5.