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Title: EFFECTS OF PHYSICAL ACTIVITY AND NUTRITION ON BONE DENSITY MEASURED BY RADIOGRAPHIC TECHNIQUES

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The primary purpose of this study was to determine the effects of various levels of physical activities and calcium intake on the bone density of 'healthy' young men and women. The bone density of the males was also compared with that of the females to determine the relationship between sex and bone density.

Forty-five male and 45 female volunteer students of Oregon State University between the ages of 20 and 25 years were randomly selected to serve as subjects for this study. Following their selection and prior to the start of the study, the subjects were classified into three physical activity groups: high, moderate, and low. Classification procedures were based on the filling out of a life-time physical activity inventory and a test of hand-grip strength. Next, each subject's average daily calcium intake was calculated from two, three consecutive day food inventory periods spaced one week apart.

Bone density was then determined through the use of quantitative radiographic technique. This involved taking x-rays of the second phalangeal segment of the small finger of the right and left hands of each subject. The two-way analysis of variance was computed to determine the difference in the bone density and calcium intake of the physical activity levels and sexes and a Pearson Product Moment Correlation Coefficient (Pearson 'r') was computed to determine the relationship between calcium intake and bone density. The .05 level of confidence was used in retaining or rejecting each of the hypotheses tested.

The results of the study showed that: a) there was a significant difference in the bone density as a function of the physical activity levels, with the Highly Active group showing a denser bone than the Moderate and the Low activity levels; b) the males had significantly denser bones than the females; c) there was not significant difference in the amount of calcium consumed per day by all the three activity levels, but the males had a significantly higher calcium intake per day than the females; and d) there was a significant positive correlation between calcium intake and bone density.

Specific amount of strenuous physical activity is, therefore, required to develop and maintain a dense (strong) bone. The stress and strain imposed upon the bone must be of sufficient magnitude as to force an increased mineralization of the bone. Up to a certain optimum, and with adequate physical stress, increased calcium intake results in increased bone density.

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EFFECTS OF PHYSICAL ACTIVITY AND NUTRITION ON BONE DENSITY MEASURED BY RADIOGRAPHIC TECHNIQUES

I. INTRODUCTION

During the last century, industrial mechanization has decreased the amount of muscular activities performed by man. Increased inactivity has led to noticeable deterioration in the structures and functions of the various organs of the body. Morehouse (51) has noted that physical deterioration due to inactivity is in proportion to the degree of sedentarianism. Decay in physical fitness is progressive because each debilitating episode leads to further lessening of physical activity.

Fractures of osteoporotic origin constitute one of the major disabling afflictions of the elderly and occur four times more frequently in women than in men. In 1968, approximately 4,000,000 hip and limb fractures occurred in the 65+ age group which then constituted about 10 percent of the population of the U.S.A. Iskrant (42) has shown that falls are the leading cause of accidental deaths in elderly white women and fractures usually of the lower limb and hip associated with "bone fragility" account for most of the deaths in this group.

Osteoporosis is, however, not limited to the aged. The study of Albanese et al., (2) revealed that subnormal bone density prevails in both sexes in a significant number of "healthy normal" persons as early as age 25. Bone, as a living tissue, adapts to environmental conditions. Daniels and Davies (23) said, "some believe that bone, like muscles, becomes stronger as greater demands are made upon it." Bone loss, as well as decrease in bone strength is strongly associated with inactivity and immobilization. Birkhead and co-workers (13) reported that the most marked change found in four healthy men during prolonged bed rest included definite increases in the excretion of calcium and phosphorus. In some cases the output of calcium more than doubled, and the increase began during the first six days in bed. Osteoporosis or bone deconditioning, due to the lack of exercise, therefore, must now be considered a major health problem.

Need for the Study

The reduction in the mass of bone in old age known as osteoporosis has received much attention, but the causation is not very clear and no satisfactory therapy is known. In all situations, loss of bone substance inevitably means reduction of bone strength and often fracture. In 1971 there were almost 2, 500, 000 patient visits for the treatment of osteoporosis, with or without fracture, in the United States (52). According to Vose (86) and Weinmann (90) the size, shape and mass of a bone determine the total load which it can support. The higher the interstitial bone mineralization, the greater the ultimate yield loading. The more porous the bone, the weaker it is.

The increase in fractures associated with automobile accidents, airplane crashes and common falls, and the decreased bone density associated with age lend urgency to questions concerning bone strength and density. The clinical magnitude of osteoporosis discloses the need for the evaluation of therapeutic measures for its prevention and management (7).

Bourne (14) suggests it is reasonable to assume that the weight of a muscle depends on activity, and muscular action determines the development of the trabecular structure in the vertebrae. According to Cureton (22), a man is physically what his activity or lack of activity makes him. He thus suggests that more time be spent studying the physical changes that activity or inactivity causes in the human body. Therefore, there is a strong need for more information on the strength of bones, especially with relation to the effect of various levels of muscular activities on the density of the bone.

The ever increasing numbers of the older population in this and other countries and rising costs of medical care make it imperative that the effect of physical activity on bone density be studied further--since it looks like inactivity or hypokinesia, a major cause of bone loss in "normal healthy" individuals, is the most practically reversible of all the causes of osteoporosis.

Purpose of the Study

The primary purpose of this study was to determine the effects of various levels of physical activities and calcium intake on the bone density of 'healthy' young men and women. In addition, a comparison was made between the bone density of the male and that of the female subjects of comparable chronological age to determine the relationship between sex and bone density.

Null Hypotheses

The null hypotheses tested in this study were:

1. There is no significant difference in the bone density and calcium intake of highly active, moderately active, and minimally active individuals.
2. There is no significant difference in the bone density and calcium intake of males and females.
3. There is no significant interaction between physical activity level and sex on either bone density or calcium intake.
4. There is no significant correlation between bone density and calcium intake.

Definition of Terms

Terms frequently used throughout this study are defined as follows:

Bone Density. Bone density is the mass of bony tissue per unit volume of anatomical bone.

Calcification. Calcification is the process by which calcium is deposited within the bone tissues.

Calcium Intake. Calcium intake is the amount of calcium an individual consumes per day.

Hypokinesia. Hypokinesia refers to subnormal muscular activities.

Ossification. Ossification is the turning of bone fibers into bone tissues.

Osteogenesis. Osteogenesis refers to all the factors that are concerned with the formation and growth of bones as organs.

Osteomalacia. Osteomalacia is the failure of bone to ossify due to a reduced amount of available calcium. Also known as adult rickets.

Osteoporosis. Osteoporosis is deossification with absolute decrease in bone tissue, resulting in enlargement of marrow and Haversian spaces, decreased thickness of cortex and trabeculae, and structural weakness.

Phalanx 5-2. Phalanx 5-2 refers to the second phalageal segment (middle) of the small finger.

Delimitations of the Study

The study was completed on 45 male and 45 female students of Oregon State University, who were between ages 20-25 years.

The subjects' life-time activities, rather than a specific training program, were considered in determining their level of physical activity.

Because of apparent racial differences in bone density, this study was limited to caucasian Americans.

Limitations of the Study

The primary limitation of this study was the small number of college students ages 20-25 years willing to serve as subjects.

The subjectivity of most inventories is a well-known factor. The authenticity of the information given in the physical activity and nutrition inventories was thus based on the undoubted sincerity and knowledge of each subject.

II. REVIEW OF RELATED LITERATURE

Various limitations of the available procedures for measuring the state of mineralization of various parts of the skeleton have made osteoporosis a syndrome of undefined pathogenesis and etiology. Recent improvements in the techniques for measurement of bone mass have, however, allowed for some studies on the effects of factors like nutrition, age, sex and physical activity or inactivity on the development of the bone. The available literature is discussed as follows.

The Bone Structure

Osteogenesis refers to all the factors that are concerned with the formation and growth of bones as organs. Bone originates from mesoderm. The mesoderm also gives rise to the muscular system. The process of ossification is just one phase of osteogenesis (33).

Bones begin as mesenchymal condensations during the embryonic period (the term condensation refers to an increase in the number of cells or fibers, or both). Some condensations are more fibrous. Ossification in them, forms the membrane or dermal bones. Most condensations are, however, cellular. These condensations become chondrofied, and form hyalin cartilage that have approximately the shapes of the future bones. The formation of bone as a tissue is first indicated by an increase in the number of cells and collagenous fibers. The cells differentiate into osteoblasts which then form an organic matrix called ostreoids, in which bone salts are deposited. Some osteoblasts are trapped in the matrix and become osteocytes. Others divide and form more osteoblasts on the surface of the bone (33, 50:3).

Osteocytes are an essential constituent of bone, for when these cells die, the matrix around them, although persisting for some time, eventually crumbles and is removed to be replaced by living bone. Osteocyte death is, therefore, synonymous to bone death (14:6).

The osteoclast is a giant cell associated with bone removal. It has a variable number of nuclei, often fifteen or twenty. This cell is usually found in close relation to resorption of bone and frequently lies in grooves of the bone (50:31). This bone salt consists principally of calcium phosphate (14:9).

The bone is a living tissue and thus human bones of any age have a rich nerve supply. These nerves, according to Sharman (76), are usually associated with arterial vessels. The nerves are probably derived from the autonomic system and are concerned with the regulation of blood flow. The study of Post and Shoemaker (62) showed that the rate of blood flow through the marrow of bone was much greater than the rate of flow through resting muscle and was almost as great as that reported for brain tissue. Cumming and Nutt (21) found that the erythroid marrow of bones in animals tested was about two percent of the total body weight, but almost eight percent of the cardiac-output flowed through this tissue. Adrenaline, however, reduces the capillary blood flow through bone (16).

Being a living tissue, the bone is capable of rapid adjustment to changing demands. It has the advantage over cartilage of greater strength and rigidity, yet it has the capability for rapid remodeling and reconstruction as occasion demands. Bone is versatile, having many functions. It is supportive and locomotive. It is also hemopoetic and serves as a mineral reservoir. Bone is not a static tissue. On the contrary, it is constantly being reconstructed or remodeled throughout life. This is a process in which old matrix is removed at one point while new matrix is deposited. Bone has a very active metabolism with regard to the replacement of its mineral phase as determined by isotope studies. Reports edited by Bourne (14:288) indicated that about twenty-nine percent of the inorganic phosphate of the epiphysis was renewed every fifty days.

Osteomalacia and Osteoporosis

In 1968, Iskrant (42) reported that approximately 4,000,000 hip and limb fractures associated with "bone fragility" occurred in the U S.A. in the 65+ age group and the radiographic data on 369 males and-666 females by Albanese et a. (2) in 1969 indicated that subnormal bone density is more prevalent in "healthy normal" subjects than heretofore realized. According to the National Disease and Therapeutic Index-Diagnoses (52), in 1971 there were about 2,500,000 patients visits for the treatment of osteoporosis. All these point to the fact that "bone fragility" has become a very important health problem.

Osteomalacia (by definition, "soft bones") is not as common as osteoporosis. The radiological appearance of osteomalacia in the infant and child prior to the closure of the epiphyseal plate usually poses no problem. In the adult, the appearance of osteomalacia is not very specific. The appearance of the decalcification is quite uniform and the bones usually show a lack of trabecular structure. The cortex also becomes thin. Non-calcified matrix is present, so that by chemical analysis one finds a decrease in mineral content per unit volume. Pseudofractures are present in advanced adult osteomalacia (80).

Osteoporosis by definition is an abnormal porousness or rarefaction of bone by enlargement of its canals or the formation of abnormal spaces. It has generally been considered as a decrease of bony tissue in which the primary disturbance is a lack of bone matrix formation with a corresponding reduction in mineral content parallel with the loss of bone matrix (80). According to Nordin et al., (56), osteoporosis can best be defined as a condition in which there is a reduction in the volume of bony tissue per unit volume of anatomical bone (reduced bone density).

Causes of Osteoporosis

Riggs (69) and Guyton (35) indicated that the major common causes of osteoporosis are:

i. Bone Loss of Disuse, from reduced activity of age, immobilization of disease, e.g. strokes, cardiac deficiencies, prolonged bed rest and occupation in confined quarters.

ii. Hormonal Imbalance, of menopause in females (and males) and prolonged corticosteroid therapy. Albanese et al (2) state that prolonged exposure to corticosteroids for the clinical management of arthritic diseases is definitely associated with the onset of severe disabling osteoporosis.

iii. Calcium Deficiency, of poor diets (economic or cosmetic fad) and uncompensated calcium loss of multiple pregnancies. Poor protein diet also contributes to osteoporosis.

Altitude and Weightlessness. Although Hunt and Schraer (40) observed large skeletal changes in rats during altitude acclimatization resulting in a significant increase in the size of bone marrow cavity and a lower mean femur density than that of the control, a later study, by Gong (34) showed that neither the marrow volume nor the bone (trabeculae and cortical) volume was altered by altitude change. Mack et al. (47) and Nicholson (53) found that a "new" condition, namely, weightlessness, also produces loss of bone substance easily detected radiologically.

Whatever the cause of osteoporosis, a decrease in matrix is the end result. There is the thinning of the cortex, and loss of bone mass which occurs with normal aging. Vose (86) believes that osteoporosis results in a decrease in total bone strength. Although the intrinsic strength of finite regions with the cortex may be thirty percent higher than normal bones, the whole bone strength may be reduced by as much as forty percent in osteoporosis.

Measurement of Skeletal Changes

Increasing interest in the problem of bone densitometry has been apparent for some years. Because of all the concern about what is going to happen to the skeleton under the condition of weightlessness, and the effects of various factors on the skeleton, be they hormonal, nutritional or whatever, bone densitometry has been a problem of great interest over a long period of time to physiologists and clinicians (93). Some of the methods used in detecting skeletal changes are reviewed as follow:

Ash Weight or Calcium Content Technique

This is one of the earliest methods in the study of the bone content and it is this destructive technique which has limited the study of bones to rats' and dogs' skeleton. In this method, the animal is usually sacrificed and the bones dissected. The chosen bone is then measured for its length, needed sections are cut, freed of marrow, weighed wet, ashed, and the residue analyzed for calcium (25). Obviously, this is not a practical method for diagnosing skeletal changes in living humans.

Biochemical Methods

(a) Metabolic Balance.

One of the principal methods used for measuring skeletal changes in human beings over some considerable period of time has been the metabolic balance. This is the use of urinary excretion of calcium as a measure of bone loss. But, according to Whedon (93), metabolic balance studies for calcium, extending over several weeks or even several months, throw some light on only a portion of the total biochemical condition. The reports by Albanese et al. (3) and Reshef et al. (67) have made it clear that urinary excretion of calcium does not always correlate with the presence of radiologically diagnosed osteoporosis.

(b) Valine Intolerance.

In this technique, patients are given a solution containing L-Valine to drink after collection of blood sample. An hour later, a second blood sample is collected and percentage change in plasma valine is recorded (58). Albanese et al. (7) preliminary observations suggest that a promising correlation exists between valine intolerance and bone loss in terms of 5-2 phalange bone density determination; that osteoporosis may be associated with an endogenous deficit in protein metabolism as reflected by valine intolerance. However, Albanese and co-workers agree that the clinical significance of this metabolic abnormality in the management of bone loss remains to be clarified.

Iodine-125 Bone Densitometry

An instrument using radioactive I^{125} has been devised by Strandjord and Lanzl (80) for non-destructive testing to determine the condition of the bone mineral in the skeleton. This is accomplished by studying the transmission through a single finger bone (the second phalanx of the third digit on the left hand) of the radiation emanating from I^{125}. The smaller the bone mineral content, the higher will be the transmission of the radiation through the bone. A lower value of bone mineral content can be due to a thinner bone, a bone of lower density, or a combination of both. A change in the effective atomic number of the bone would also result in a change in the radiation transmitted through it.

The entire unit is normally programmed to make transmission measurements across the entire width of the finger automatically. The finger is held immobile by two parallel plates. Measurements are made at 1 mm intervals until the entire finger has been measured and expressed as linear coefficient of absorption of total bone. A thin bone will give a lower linear coefficient of absorption.

Sonic Measurement of Bone Mass

This method uses sound velocity based on the principle that the velocity of sound varies according to the density and elastic properties (for solid) or compressibility (for liquids and gases) of the medium through which it passes, and is greater in solid than in liquid media. Thus, when a pulse of sound is passed through a limb which contains bone and soft tissues, the velocity will be greater in the bone than in the soft tissue and the time necessary for sound to traverse the limb will depend on the distance of the sonic path in each tissue. The transit time is used to measure the amount of bone present.

Clayton et al. (19) used a modified form of the 'sonodistometer' an instrument developed by Rushmer et al. (72) in measuring bone density. The difference between transmission time through bone and soft tissues and through soft tissues alone can be compared to the transmission through a bone chip of known composition. This allows estimation of the mass of calcium in the bone examined. When the dimensions of the bone are known (from an x-ray), its density can be estimated.

This method is found to be more accurate with cortical bones than with trabecular bones. The trabecular bones present much more technically difficult measurement because of loss of a large part of the sonic energy, presumably from reflection and formation of sheer waves as the beam is passed through the many interphases between bone and marrow. Even when these technical difficulties are overcome, the resulting measurement fails to predict accurately the calcium content. Generally, the sonic measurement gives a value which usually results in too high a prediction of the mass of calcium present (19).

Morphological Measurements

This is the measurement of the thickness of the cortex of a cortical bone at its midpoint or the thickest point of the cortex, and expressed as a percentage of the total diameter of the bone. The thickness of the medial and lateral cortices of the bone, e.g. femoral shaft, at the thickest part of the cortex is measured. The sum of these two thicknesses is divided by the total shaft diameter at the same level. The fraction multiplied by 100 gives a ratio which has been variously termed the femoral or humeral score or the cortical index (80).

The studies by Vosa et al. (87) and the experiment of Bauer et al. (11) clearly demonstrated the mobility or availability of the mineral in trabecular bone, in apparent contrast to that in cortical bone. The peripheral bones may be far less responsive to changes in the total mineral content of the skeleton than the trabecular bone. Thus the measurement of the mineral content of the trabecular bones is demonstrated to be a more accurate measure of the density of the total skeleton than the thickness of the cortex of the peripheral bones.

Nordin et al. (56) believe that loss of cortical bone can generally be determined by morphological measurements (except in the spine). Nevertheless, it was apparent in their study that morphological measurements are relatively insensitive measures of osteoporosis. According to Strandjord (80), even though the morphological measurement has some clinical application, it is not a sensitive indicator of demineralization, as the changes cannot usually be easily discerned until after a loss of twenty percent of bone mass.

Quantitative Radiographic Densitometry

One of the many biomedical applications of the discovery of x-rays by Roentgen in 1895 is the accurate assessment of the bone mineral content of a living subject. Quantitative radiographic densitometry has been one of the most thoroughly investigated nondestructive methods for the determination of bone minerals in vivo (70). The successful development of this method has assisted significantly in the recognition of normal skeletal variation, in the recognition of the incipient or latent stages of pathological conditions involving bone and in the early responses of osseous disorders to therapy (74).

An apparatus was developed by Brown (15) in 1949 which greatly facilitated the extraction of information from suitably exposed and standardized roentgenograms. This apparatus was referred to as "a bone density computing machine" and formed the basis of the equipment developed under the supervision of H. Schraer (74) in 1957.

The roentgenograms of the bone to be evaluated are taken with any medical x-ray machine which is operable in the 50 to 60 kv range. A small focal spot is desirable (1 mm). No screen x-ray film in cardboard holders is employed. A specially designed, standardized aluminumzine alloy wedge is simultaneously exposed with the anatomical part of interest. Typical exposure factors for an adult hand would be 55 kv. peak and 18 milliampere seconds (MAS) using a 2 mm aluminum filter. The carefully developed film is then analyzed in the densitometer (74). This method was validated by the studies of Baker and Schraer (1958) (10) and Schraer et al. (1959) (75).

In 1969, Albanese et al. (2) reported an improved quantitative radiographic survey technique following the experience of Schraer and his associates. The new technique is described fully in Chapter III of this study. This new technique was validated by the studies of Albanese et al. (7, 3) in 1972.

According to Albanese et al. (2), the limitations of various procedures for detecting bone loss make osteoporosis continue to be a syndrome of undefined pathogenesis and etiology. Metabolic balance studies for calcium, extending over several weeks or even several months, throw some light on only a portion of the total biochemical condition (93). Tracer studies with Ca^{45}, Ca^{47} or Sr^{85} have failed to reveal differences in bone formation between osteoporotic and normal subjects (54). Histologic studies which involve serial bone biopsies have proved difficult to perform and interpret. The $Iodine^{125}$ (80), tetracycline labeling (49) and sonic (19) procedures do not appear to be readily adaptable to the ambulatory subject. Application of the foregoing procedures requires hospitalization or confinement of the subjects.

The use of quantitative radiography, however, allows one to assign a discrete number value to a particular subject with greater precision and accuracy. Albanese et al. (2, 3) reported a linear correlation between radiographically determined bone density, residual calcium content and bone weight of chicken bones. As the density decreases, so did milligrams of calcium in bone. Nordin et al. (56) also state that loss of trabecular bone can only be detected by changes in the absorption of x-rays or other radiation by the bone, unless the scanning method of Virtama and Kallio (85) can be applied to man. These circumstances leave radiographic densitometry as the most practical procedure for survey purposes.

Site of Measurement

The density of several skeletal sites have been considered as representative of the density of the total skeleton. The studies of Vose et al. (87) and Bauer et al. (11) have demonstrated clearly that the mineral content of the trabecular bones is a more accurate representative of the total skeleton than the thickness of the cortical bones.

Vose (88) explained that the spine has long been considered the densitometric area of choice. The major technical problem that has hindered vertebral densitometry is the complexities resulting from the effects of the superimposed, large and variable amounts of surrounding soft tissue and sometimes the nonuniform bowel contents on the bone image. Virtama and co-workers (84) have demonstrated good correlation of the mineral content of the bones of the hand with that of the rest of the skeleton. Schraer (74) and Mack (46) demonstrated that determination of radiographic density of the middle phalanx of the fifth digit provides a practical and useful criterion of incipient bone loss or overt osteoporosis.

The middle phalanx in the fifth digit was selected as an anatomical site for evaluation because it represents a bone which contains a substantial amount of compact skeletal tissue and because it is easily accessible for radiographing. The selection of a single phalanx in the fifth digit was made because of the finding that bone mass values of other phalanges in the same subject were closely correlated (46, 74). Recent comparative analysis has demonstrated valid correlation between phalanx 5-2 bone loss densitometric measurements and vertebral radiographically diagnosed osteoporosis. Based on information to date, Albanese et al. (3) suggested that next to vertebral densitometry, the "site of choice", so to speak, are phalanx 5-2 and the 3 cm site of the radius, the olecranon and calcaneus.

Nutrition and Bone Development

Riggs (69) has identified poor diets resulting in calcium and protein deficiencies as one of the causes of osteoporosis. According to Park (66), when nutritional disturbances in the young animal become so severe that nutrients material is inadequate to supply all the needs, preferance is given to those organs on which continued existence depends. In a crisis, bones cease to grow but proceed to grow again when the crisis is over. This pause in growth leaves marks in growing bones, as seasonal sapless periods leave their marks in trees in the form of rings. Lister and McCance (45), however, pointed out that the ability of such animals to grow after the period of under-nutrition is over is limited and the animals fail to achieve the full stature of their normally-raised litter-mates.

Adams (1) showed that when pigs are subjected to severe, prolonged calorie and protein deficiency, growth is retarded; the bones are small and are abnormal in structure and composition. With protein deficiency, the long bones are longer and wider than after a comparable period of calorie deficiency. This increase in the size of the bone is, however, associated with a loss of trabecular and cortical bone.

The alarming rate of inadequate dietary calcium intake in the U.S. population coincided with the increase in patient visits for the treatment of osteoporosis, with or without fracture (52). A U.S. government report (27) indicated that 30.5% of the entire American public consumes less than 800 mg of calcium a day, which is the 'Standard Recommended Daily Allowance.'

Hurxthal and Vose (41) demonstrated in 237 female patients that those consuming less than 350 mg calcium daily had almost 20% less in mean ash content of wet bone weight than females consuming 800 gm of calcium or more daily. Some investigators have, however, maintained that the 800 mg RDA is not adequate, stating that daily normal losses of calcium are 1,100 mg, thus requiring an increase of 35% in the RDA factor just to achieve calcium balance (32).

With respect to female demographic analysis of calcium dietary habits, the intake of daily calcium progressively diminishes from age 29 years and over (57). The studies of Albanese et al. (3) showed that females with calcium supplements along with proper diet and normal activity do increase bone density. However, there is the evidence that calcium compounds require concomitant Vitamin D_2 for aid in absorption of Ca^+ across the intestinal cells. Avioli (9) claims, "Vitamin D is perhaps the singularly most important substance regulating the intestinal absorption of Ca in man." Vitamin D_2, which by itself is biologically inactive but is converted in the kidneys or the liver to biologically active metabolites, is important in specifically transporting intestinal calcium across the luminal cell membranes (9, 35, 81).

Rich and Ensinck (68) reported positive changes in calcium balance and a decreased rate of excretion of calcium in the urine of a patient with widespread Pagent's disease when put on a high dose of sodium fluoride. Similar improvements in calcium metabolism were obtained in several patients with osteoporosis. According to Evans (31), experimental studies with rat and cattle bones show that the breaking load, when the bone is tested like a beam, is decreased with diets low in salt, calcium and phosphorus. The breaking strength of rat bones, as indicated by the bending and torsion moments, increases with increased calcium intake up to about 0.36% Ca in the diet but greater intake has no further effect on bone strength. The breaking strength of rat bones is decreased by a radritogenic diet, although the strength can be increased somewhat if the diet is supplemented with Vitamin D. The strength, however, cannot be brought up to that of bones of animals fed on a standard diet.

Smith and Dent (78) suggest that adults have a daily requirement of Vitamin D of probably less than 100 units (2-5 ug). They, however, found that in three European patients, symptoms and signs of osteomalacia did not develop until at least seven years on the Vitamin D deficient diet.

Age, Sex and Bone Density

Age and sex have some relationship with bone density. A biological system ages if there is a progressive change in its structure or function, causing the organism to deal less effectively with its environment (36).

A study by Ranber (64) showed a decrease in the bending strength of an adult's femur with age. Some surveys by Nordin (55) showed that virtually the entire aging female population is affected with post-menopausal osteoporosis losing as much as 20 to 60 percent of bone mineral content over the 50 to 80+ years age span. The same condition is found in 5 to 10 percent of men where it is known as senile osteoporosis.

A recent survey by Albanese et al. (2) indicates that all people lose bone as they age. The density of phalanges 5-2 in young males and females (age, 5-15 years) was approximately the same. After age 15, the density of phalanx 5-2 became significantly greater in the males than in the female. In the females, the density of phalanx 5-2 reached a peak at age 35-45 years and then declined progressively as age advanced to 85-95 years. In the males, the peak was reached at age 45-55 years and the decline started at age 55-65 years. The rate of decline per decade is about 10 percent of the initial mean value in women and somewhat less in men.

In another report on the effect of a calcium-vitamin D_2 supplement and a placebo on two groups of "healthy, normal" females, 53-88 years of age, Albanese et al. (4) observed that in general, protein rejection was greater than rejection of carbohydrates or fats and dietary calcium intake was approximately 40 percent less than the 1000 mg per day indicated by the U.S. RDA (26). This confirms the findings of the University of California Division of Agricultural Sciences (57) that, with respect to female demographic analysis of calcium dietary habits, the intake of daily calcium progressively diminishes from age 29 years and over. According to Kretchmer (44), this suboptimal calcium intake may be due in large measure to the clear and prevailing aversion of this age group to milk--usually associated with a lactose intolerance due to a lactase deficiency.

Effects of Physical Activities on the Bone

A significant amount of controversy exists over the actual effects of mechanical action on the bone. As pointed out by Rarick (65), the specific role of exercise in the growth phenomenon is not entirely clear. It is known that under certain physically stressful conditions, the level of circulating somatotrophin, the growth stimulating hormone, is increased. It is also known that exercise increases both appetite and utilization of nutrients, both of which are related to growth.

Thoma (82) held the extreme mechanical view that all bone formation, even including the first bone formed in the embryo, takes place as a response of bone forming tissue to the action of stress and strain. As stress and strain increase, new bone forms with increasing rapidity until a certain optimum is reached. He held that growth in thickness, in human bones, begins when the stress and strain exceed a certain minimum which he estimated roughly to be equivalent to a weight of 6.6 grams per square millimeter of cross-section acting over twenty-four hours.

There is, however, already much evidence against this extreme view. Ollier (59) found that periosteum, transplanted from the tibia to the comb of a rooster, forms a shell of bone-clearly without the action of stress and strain.

Pottorf (63) working with puppies, performed two experiments: in the first he diminished the stress and strain exerted on one of the fore-legs of a three week puppy, by holding the leg in a sling, so that no weight was borne by this leg. At the end of three weeks he found the bones of the two fore-legs to be about the same length, while the bone in the legs walked on were considerably thicker than in the other. In a second experiment, one leg was paralyzed, thereby eliminating, in addition to the stress and strain due to the weight of the body, that due to muscle pull. After twenty days it was found, again, that growth in length had been nearly the same in the bones of the two legs, but the bones in the unoperated leg were in some places from two to four times as thick as those in the immobilized leg. This finding was confirmed by a recent study by Leyshon (45a) which showed no significant difference in the tibial lengths of rats exercised for nine weeks and sedentary rats. However, the epiphyseal plates of the exercised rats were significantly wider.

A study by Howell (39) showed that after about twenty weeks, the thickness as well as the crushing force (strength) of the bones of the used leg were more than three times greater than those of the unused leg. According to Howell, it is probable that a part of the growth in length is also dependent upon the amount of stress and strain. This appears to be increasingly important as the animal grows older, for, while growth in length in the unused bones practically kept pace with that in the used bones for six weeks after operation, thirteen weeks later, the increase in length of the bones in the used leg had been 20 to 25 percent greater than that of the bones in the paralyzed leg.

A classic study by Hearney (37) indicated that the absence of mechanical stress did not, of itself, reduce bone forming activity, but inactivity does cause a great increase in bone resorption (demineralization) resulting in the development of disuse osteoporosis. There is also a gross depression of gastrointestinal calcium absorption efficiency in the acute stage of osteoporosis. The absence of muscular activities thus results in a decrease in bone density. These findings correspond with the studies of Bauer and Carlsson (12) who attributed the disuse osteoporosis of a fractured leg to increased bone resorption, and Slack (77) who presented the data which indicated that soft-tissue atrophy following denervation could only be due to increased resorptive activity.

Inactivity and Bone Loss

Lack of physical activity has been identified as one of the principal causes of osteoporosis. Allison and Brooks (8) investigated the effects of nonuse on the foreleg bones of dogs and found that the initial changes arising from nonfunction were the same regardless of the age of the individual. However, in the adult dogs disuse resulted in bone atrophy alone but in the growing dogs bone atrophy occurred and growth was inhibited although not stopped. In the atrophied bones, the thickness of the cortex of the shaft decreased with consequent enlargement of the medullary cavity. With a long period of non-function in adult animal, the cortical bone of the shaft lost its compact structure and became more porous.

Studies by Deitrick and associates (24) showed that losses of body protein equivalent to one-half to two pounds per week were created in healthy normal young adults immobilized and kept in bed for periods of six to eight weeks. There was a prompt increase in both urinary and fecal calcium which continued and reached a maximal peak at four to six weeks. A subsequent study by Whedon et al. (94) disclosed that urinary calcium increased less rapidly during immobilization on a slowly oscillating Sanders bed.

Howard and co-workers (38) found a greater loss of body tissues in young men immobilized by fractures. An increase in urinary calcium output was observed during the period of immobilization with a dietary intake of 2.0 gm/day throughout the course of the experiment. In stroke patients, whose mobility was limited due to paralysis of either the right or the left side, Albanese et al. (6) observed protein losses equivalent to 1.5 to 2.0 lbs of muscle tissue per week. In subsequent studies, they found that protein depletion of stroke patients could be reduced in full or in part by programmed exercise and ambulation.

Klapper and Mack (43) reported calcium losses and decreased bone density incident to bed rest. Birkhead and associate (13), Mann et al. (48) and Campbell's (17) investigations show that tissue protein losses of young men, incident to immobilization, were invariably associated with marked increase in urinary calcium output--an indication of bone loss. In all instances, the onset of calcium depletion was rapid. Indeed, x-ray evidence of bone demineralization was found in the astronauts of Gemini IV following a 72-hour flight(47). Blackie and Breezy, the two dogs which the Russians flew in orbit for 22 days, lost weight, presented a wasting of muscle, very rapid heart action and raised blood and urinary calcium levels (51).

Effect of Muscular Activities on Bone Density

Muscular action may not be the sole cause, although it is believed to be the main cause of hypertrophy. According to Bourne (14), it is reasonable to assume that the weight of a muscle depends on activity, and muscular action determines the development of the trabecular structure in the vertebrae. Doyle et al. (29) found that the ash weight of the third lumbar vertebra (obtained in routine necropies) was significantly correlated with the weight of the psoas muscle.

Wermel (91) removed the radius or the tibia from various young animals and described the changes seen two to four months after the operation. The remaining bone, ulna or fibula, on the operated side was considerably thickened but also shorter than that on the control side. He explained that the thickening may be attributed to increased stresses on the remaining bone, but this is not the whole explanation since the ulna thickened even if the nerves to the limb were cut to reduce muscular activity. But the weight bearing effect is still there. Ross (71) described a similar situation in which a laborer had lost all the fingers of his right hand except the little finger. When he was seen 30 years after the accident, the remaining phalanges and corresponding metacarpal had greatly increased in size and the man had a powerful and useful finger. This simple observation shows that bone adapts to increased loads by an increase in both wall thickness and diameter.

In a study by Saville and Smith (73), bipedal rats (that is, without forelimbs) developed more muscle on the hind limbs and heavier and stronger femora. Wolffson's (96) experiment showed that after removal of scapular muscles, the shape and size of the scapular were considerably diminished as compared with the control, unoperated side. Watt and Williams (89) provided another illustration of the effect of activity. Their rats fed on a rough diet requiring considerable mastication had heavier and thicker mandibles, especially at the sites of muscular attachment, than had rats on a soft pappy diet. Espenchade (30) cited reports of studies at the University of Gotenberg, in which physiologists have found changes as a result of exercise in the bones and connective tissues of animals. A series of experiments demonstrated an increase in the amount of mineral salts present. These changes were all directly related to exercise. The changes were lost, however, if exercise was reduced or discontinued.

Summary

The need to consider bone loss of osteoporosis an important health problem, especially among the aged, is well established by the various studies cited. Although processes for repairing degeneration are known to exist in normal cells, the expression of senescence suggests that the repair rate cannot parallel the rate of degeneration. Unfortunately, modern science and technology has not come up with anything to retard the aging process.

While substantial efforts have been made to support the concept that osteoporosis results from chronic negative calcium balance, conversion to positive calcium balance has not been uniformly associated with increases in radiological bone density. Indeed, it has been found that there are patients on low calcium diets who do not exhibit symptoms of osteoporosis and that there are patients with osteoporosis whose diets include adequate levels of calcium (92, 54). This is not to say that nutrition does not play a part in bone density. Although Speights (79) found significantly greater breaking strength and dry weight in the femur of exercised (running) rats than in those of unexercised rats both groups on limited feed, he found a more significant difference between the growth and development of the bones of exercised rats on unlimited feed and those of unexercised rats on limited feed, the former growing and developing better than the latter.

The studies of Hovell (39) and Pottorf (63) have established that bone density is dependent, to a large extent, upon the amount of stress and strain exerted upon the bone. This applies to the growth in thickness of the trabeculae, once they have been laid down, as well as to that of the compacta.

Physical inactivity has been identified as the most notorious cause of osteoporosis. It also produces atrophy of the muscle and causes a general loss of calcium. Hearney (37) showed that inactivity results in a gross depression of gastrointestinal calcium absorption and a great increase in bone resorption. It has also been demonstrated that fecal calcium excretions are very nearly equal to intake in paralyzed subjects (95). In all these situations, loss of bone substance inevitably means reduction of bone mass and bone strength and often fractures.

It is therefore reasonable to believe that bone growth, particularly appositional growth and increase in density, occurs to support the stress imposed by the contractile force of the muscles or by the load the bone is asked to bear. According to Rarick (66), muscles without nerve supply will atrophy and the bones to which these muscles are attached will lose calcium. Thus, a minimum of physical activity is needed to maintain the integrity of both muscle and bone tissue.

III. METHODS AND PROCEDURES

This study was conducted to determine the effects of various levels of physical activities and calcium intake on the density of the bones of 'healthy' young men and women. The relationship between sex and bone density was also tested by comparing the bone density of the male subjects with that of the female subjects.

Subjects

The subjects for the study were ninety 'healthy' male and female college students between the ages of 20 and 25 years. All subjects were volunteer students enrolled in various Schools at Oregon State University during the Fall term of 1976. They thus represented a cross-section of students of this age group.

Test Design

All qualified volunteer students filled out a life-time physical activity inventory and were administered a hand-grip strength test. The results of both the inventory and strength tests were used to classify the subjects into three physical activity levels: (1) Highly active Group, (2) Moderately Active Group, and (3) Lowly or Minimally Active Group. Fifteen male and 15 female subjects were randomly selected from each group for a total of 90 subjects.

The selected subjects were then tested for bone density and calcium intake. The scores of High, Moderate and Low physical activity levels (males and females) were contrasted to determine the effects of physical activity, calcium intake and sex on the subjects' bone density (see Figure 1).

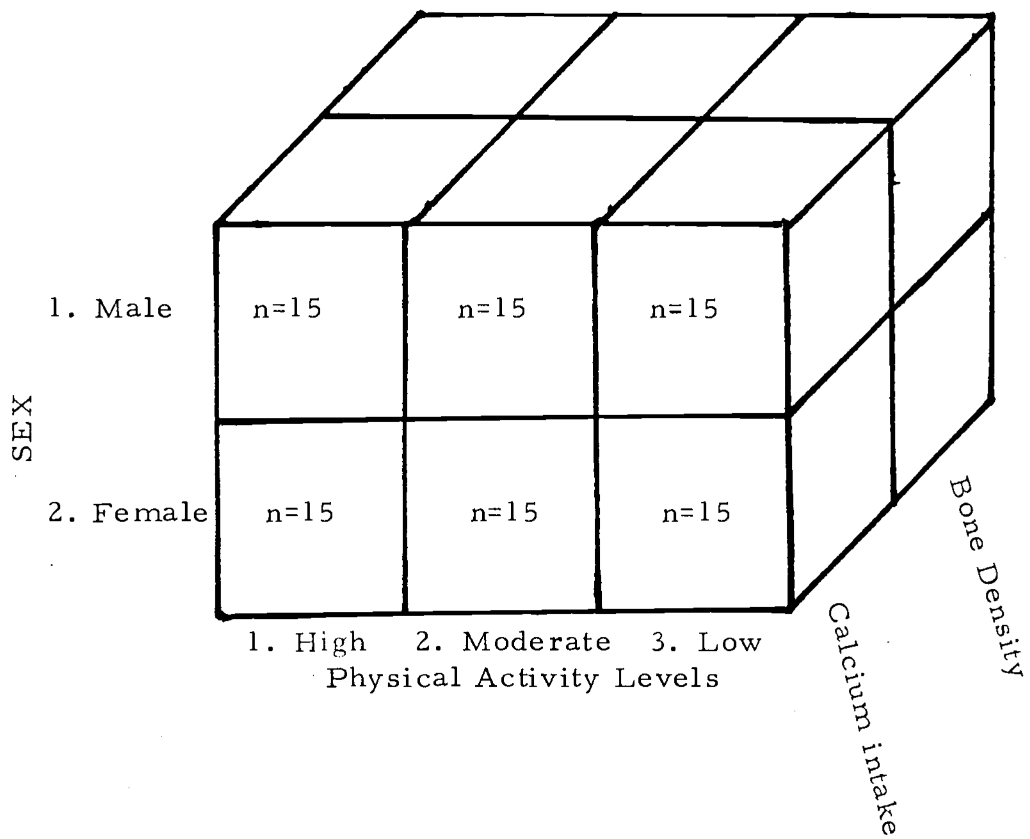

Figure 1. Design Matrix.

The two-way analysis of variance was computed to compare the scores of the physical activity levels and sexes. The null hypotheses tested were:

1. There is no significant difference in the bone density and the calcium intake of the three physical activity levels.

$$H_0 : \mu_1 = \mu_2 = \mu_3$$

$$H_1 : \mu_1 > \mu_2$$

$$H_2 : \mu_2 > \mu_3$$

2. There is no significant difference in the bone density and calcium intake of males and females.

$$H_0 : \mu_1 = \mu_2$$

$$H_1 : \mu_1 > \mu_2$$

3. There is no significant interaction between physical activity level and sex on either bone density or calcium intake.

The Pearson Product Moment ("r ") Correlation Coefficient (Pearson 'r') was computed to test the fourth null hypothesis.

The .05 level of confidence was used in retaining or rejecting each of the hypotheses. The Least of Significant Difference - "L.S.D. Test" - was applied to indicate the exact source of the significant difference where H_0 was rejected in the first two hypotheses tested.

Testing Procedures

Physical Activity Level

All anthropometric measurements and strength tests took place in the Human Performance Laboratory, Langton Hall, of Oregon State University.

Height and Weight. Each subject was weighed in his or her running shorts and socks without shoes, on a caliberated Healtho-meter Scale and heights were measured on the same scale. Subjects' weight were read to the nearest quarter-pound and heights were read in feet and inches to the nearest quarter-inch.

Physical Activity Inventory. Each subject filled out a Physical Activity Inventory (Appendix A) indicating all his/her past and present regular physical activities, the intensity and frequency of each activity.

Hand Grip Strength Test. Based on the reports by Tuttle (83) and Clarke (18) of a .67 correlation between maximum grip strength and grip strength endurance index; and a .83 correlation between strength index and physical fitness index respectively, the Grip Strength Test was used to supplement the information given by the subjects in the physical activity inventory. Both were used to divide the subjects into the three physical activity levels.

Calibrated Lafayette's Hand Grip Dynomometers were used. Each subject had three trials with his or her dominant hand, with 15 seconds rest between trials. The best of the three trials was recorded in Kilograms.

Grouping

Highly Active (HA). This group was composed of highly physically active individuals who participated in regular strenuous physical activities e.g., football, wrestling, soccer, track, basketball (minimum six hours a week) and who had a grip strength score of 60 kg or more (males) or a score of 40 kg or more (females).

Moderately Active (MA). In this group were individuals who participate in moderately strenuous physical activities on a regular basis (minimum two to three hours a week) and had a grip strength score of between 55 and 60 kg (males) or between 34 and 40 kg (females).

Lowly Active (LA). This group was composed of subjects who never participated in any strenuous physical activities on a regular basis and who had a grip strength score below 55 kg (males) or below 34 kg (females).

Calcium Intake

Each subject filled out a Nutrition Inventory (Appendix B) in which they recorded all they ate and drank for three consecutive days. A week after the first record, subjects filled out another three consecutive days' record of their food intake.

From the six days' record, each subject's average daily calcium intake was calculated. Scoring was done at the Burke Rehabilitation Center, White Plains, New York. Calcium intake was expressed in milligrams per day.

Bone Density Measurement

The Quantitative Radiographic Technique described by Albanese and co-workers (2,7) was used in this study. This is a radiographic measurement of the second phalangeal segment of the small finger (referred to as phalanx 5-2), of the right and left hands of each subject.

Apparatus and Equipment

1. X-ray Machine. A dental x-ray machine-Ritter Modulex, Model G3 was used. Operating at 65 kilovolts and 10 ma, the exposures were made a distance of 8 inches (20 cm) from the cone collar to the subject's phalanx and exposure time was 1.25 seconds (Figure 4).
2. Aluminum Wedge and Plate Holder. The wedge consists of eight steps with increments of 20 thousandths of an inch

(0.55 mm) each and is machine tooled from 6061 aluminum alloy within a tolerance of one thousandth of an inch (Figure 2).

3. Film. Radiatized dental films (1-1/4 x 1-5/8" EK Co. #DF-7) were used. Each film was placed in the slot end below the aluminum-wedged steps and fitted below the phalanx 5-2 on the lucite part of the holder.

4. Densitometric Apparatus. The densitometric apparatus at the Burke Rehabilitation Center, White Plains, New York, was used for the scanning of the films (Figure 3).

Procedure. The subject's little finger was placed on the aluminum wedge holder flush with the steps. An x-ray was taken of the second phalangeal segment (referred to as phalanx 5-2) of the right and left hand (Figure 4). The phalanx 5-2 was chosen for the practical as well as valid reasons given in Chapter II of this paper.

The x-ray of the subjects' fingers were taken in the office of Dr. J. Bowman (dentist) in Corvallis, Oregon; and the processing and photometric analysis of the films were done by the Burke Rehabilitation Center in White Plains, New York.

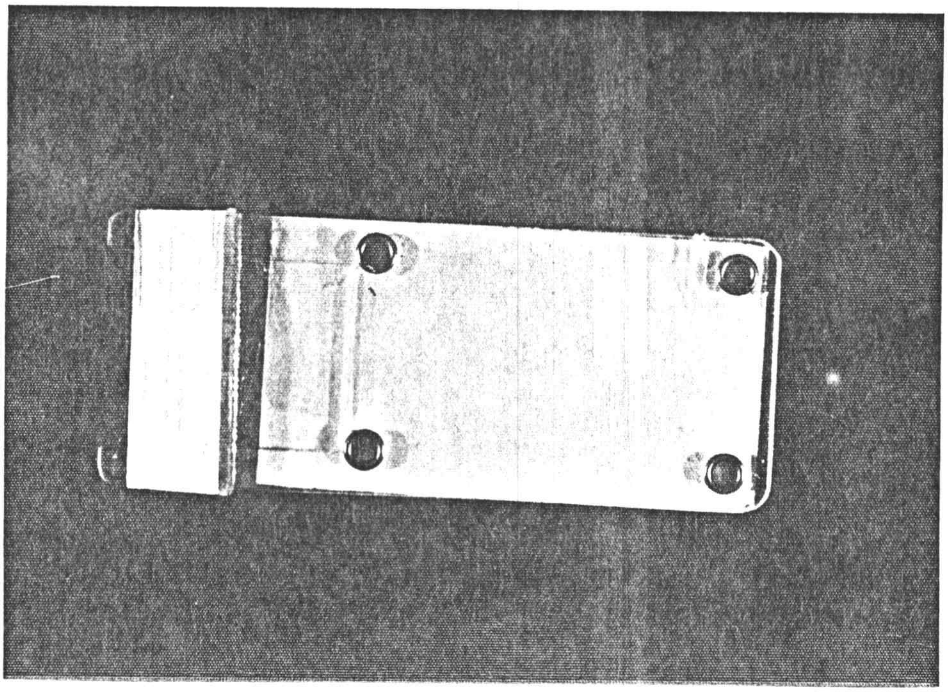

Figure 2. Aluminum wedge and plate holder.

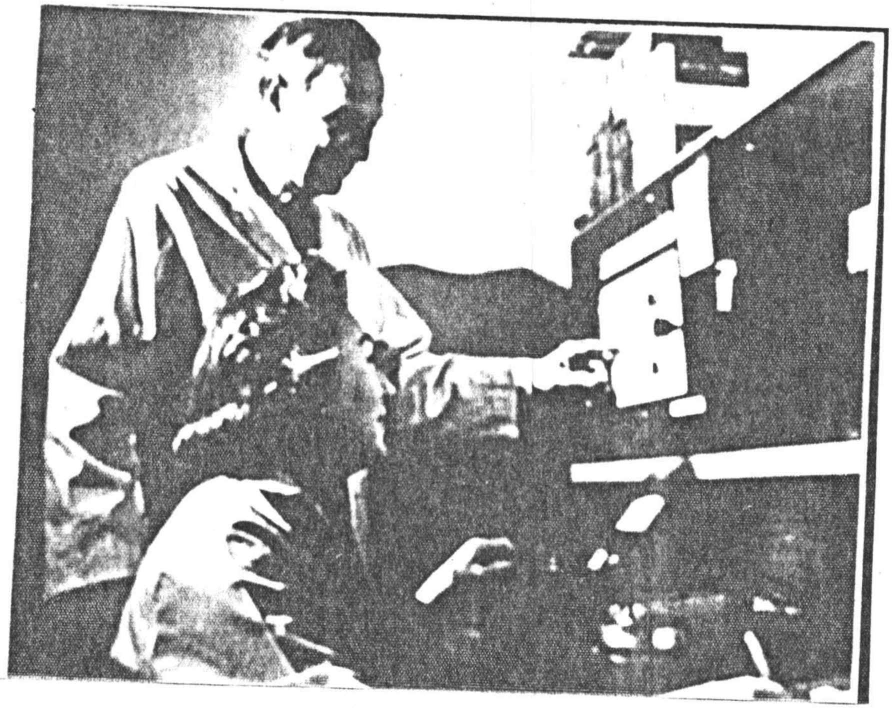

Figure 3. Photo densitometer. (Courtesy of Burke Rehabilitation Center, White Plains, New York.)

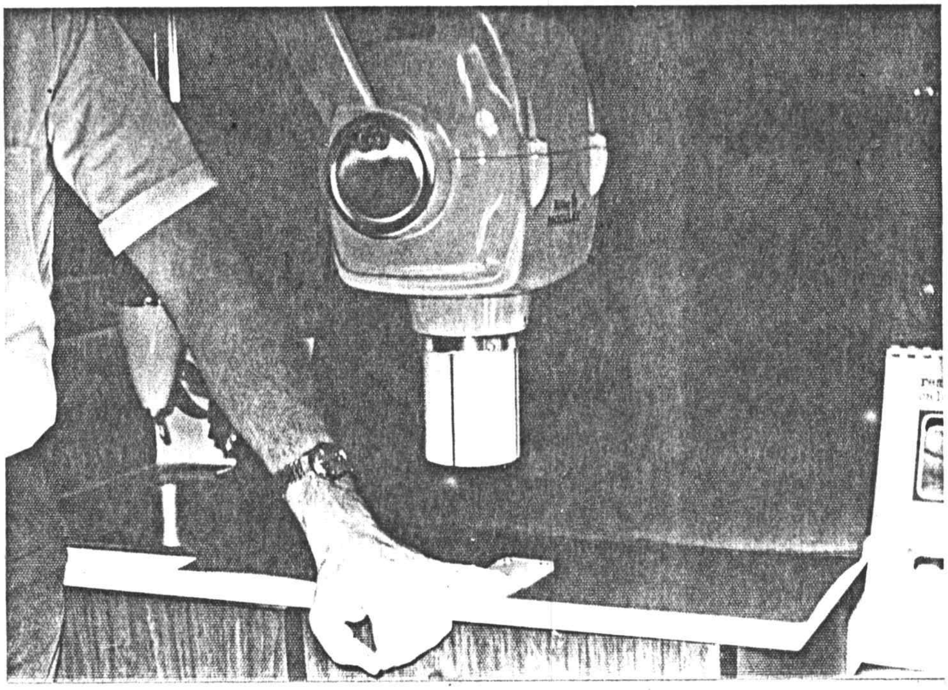

Figure 4. X-ray exposure.

IV. ANALYSIS AND DISCUSSION OF DATA

The primary purpose of this study was to determine the effects of various levels of physical activity and calcium intake on the bone density of 'healthy' young men and women. A comparison was also made between the bone density of the male and that of the female subjects of comparable chronological age to determine the relationship between sex and bone density. Forty-five male and forty-five female volunteer students of Oregon State University were subjects for the study. All subjects filled out a life-time physical activity inventory and were administered a hand-grip strength test. The results of the inventory and strength tests were used to divide the subjects into three physical activity levels: High, Moderate and Low. The subjects were then tested for bone density and calcium intake. Table 1 shows the physical characteristics of the subjects.

Table 1. Physical characteristics of subjects.

Sex	Variable	$\bar{x}$	S.D.	Range
Male (n = 45)	Age (yrs)	21.40	1.36	20-25
	Body weight (lbs)	169.41	23.53	122-223
	Height (ins)	70.06	2.75	64-75
Female (n = 45)	Age (yrs)	21.36	1.15	20-24
	Body weight (lbs)	133.29	15.17	115-173
	Height (ins)	65.14	1.98	59.5-69

Statistical Treatment

The two-way analysis of variance was computed to compare the scores of the physical activity levels and sexes, and a Pearson Product Moment Correlation Coefficient (Pearson 'r') was computed to test the relationship between calcium intake and bone density. The .05 level of confidence was used in retaining or rejecting each of the hypotheses tested.

Presentation of the Findings

The statistical comparison of the findings in each of the measured variables is presented and discussed in the following divisions: (1) Difference in bone density - by physical activity levels and sex; (2) Difference in calcium intake - by physical activity levels and sex; and (3) Correlation between calcium intake and bone density.

Bone Density

Analysis of variance treatment of the bone density scores (Table 2), revealed a significant difference in the bone density of the physical activity levels ($F = 15.149$, 2, 84 df, $p < .001$).

Table 3 shows the sources of the significant difference. The Highly Active (HA) group had significantly denser bone than the Moderately Active and Lowly Active groups. There was, however, no significant difference between the bone density of the moderately active (MA) and lowly active (LA) groups ($p > .05$). The male had significantly denser bone than the female ($p < .001$). There was no significant interaction between physical activity level and sex ($F = 1.23$, 2, 84 df, $p > .05$). Figure 5 illustrates the group means.

Calcium Intake

The amount of calcium consumed per day by the three physical activity levels did not differ significantly at the .05 level ($F = 1.096$, 2, 84 df, $p > .05$). However, the male subjects had a significantly higher calcium intake per day than the female ($F = 21.04$, 1, 84 df, $p < .001$). There was no significant interaction between physical activity level and sex ($F = 1.12$, 2, 84 df, $p > .05$).

Correlation Between Calcium Intake and Bone Density

A Pearson Product Moment Correlation Coefficient (Pearson 'r') analysis, showed that there was a low but significant positive correlation between the amount of calcium consumed per day and the density of the bone ($r = .343$, 88df, $p < .001$). This positive relationship is depicted by Figure 7.

Table 2. Analysis of variance table for bone density.

Source	df	Mean Squares	F
Physical Activity	2	1783.66	15.15*
Sex	1	7102.23	60.32*
Physical Activity x Sex	2	144.98	1.23
Error	84	117.74	
Total	89		

* Significant at .001 level.

Table 3. Summary of bone density scores. (Ins. x 10^{-3}).

Source	Group	$\bar{x}$	S.D.	$\bar{x}$ Difference
Physical Activity	High	128.00	17.57	HA - MA = 10.98*
	Moderate	117.02	12.07	MA - LA = 3.89
	Low	113.13	11.90	
Sex	Male	128.27	13.50	17.77*
	Female	110.50	11.40	

* Significant at .001 level.

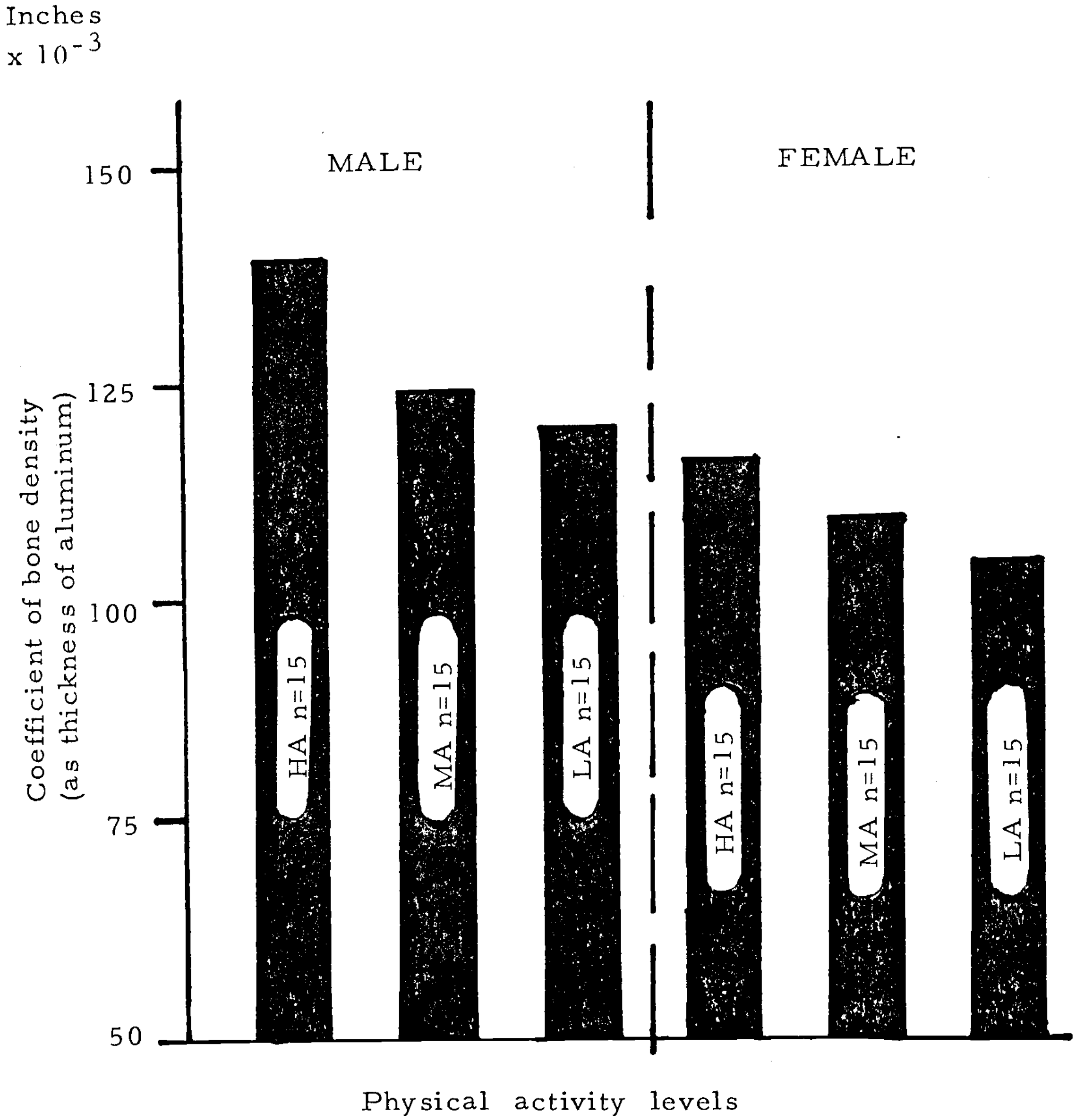

Figure 5. Mean bone density by physical activity levels and sex.

Table 4. Analysis of variance table for calcium intake.

Source	df	Mean Squares	F
Physical Activity	2	134786.48	1.10
Sex	1	2587756.90	21.05*
Leval x Sex	2	138149.03	1.12
Error	84	122939.03	
Total	89		

* Significant at .001 level.

Table 5. Summary of calcium intake scores (mg/day).

Source	Group	$\bar{x}$	S.D.	$\bar{x}$ Difference
Physical Activity	High	845.20	373.52	HA - MA = 100.47
	Moderate	744.73	375.66	MA - LA = 26.63
	Low	718.10	417.39	
Sex	Male	938.91	442.00	339.13*
	Female	599.78	227.47	

* Significant at .001 level.

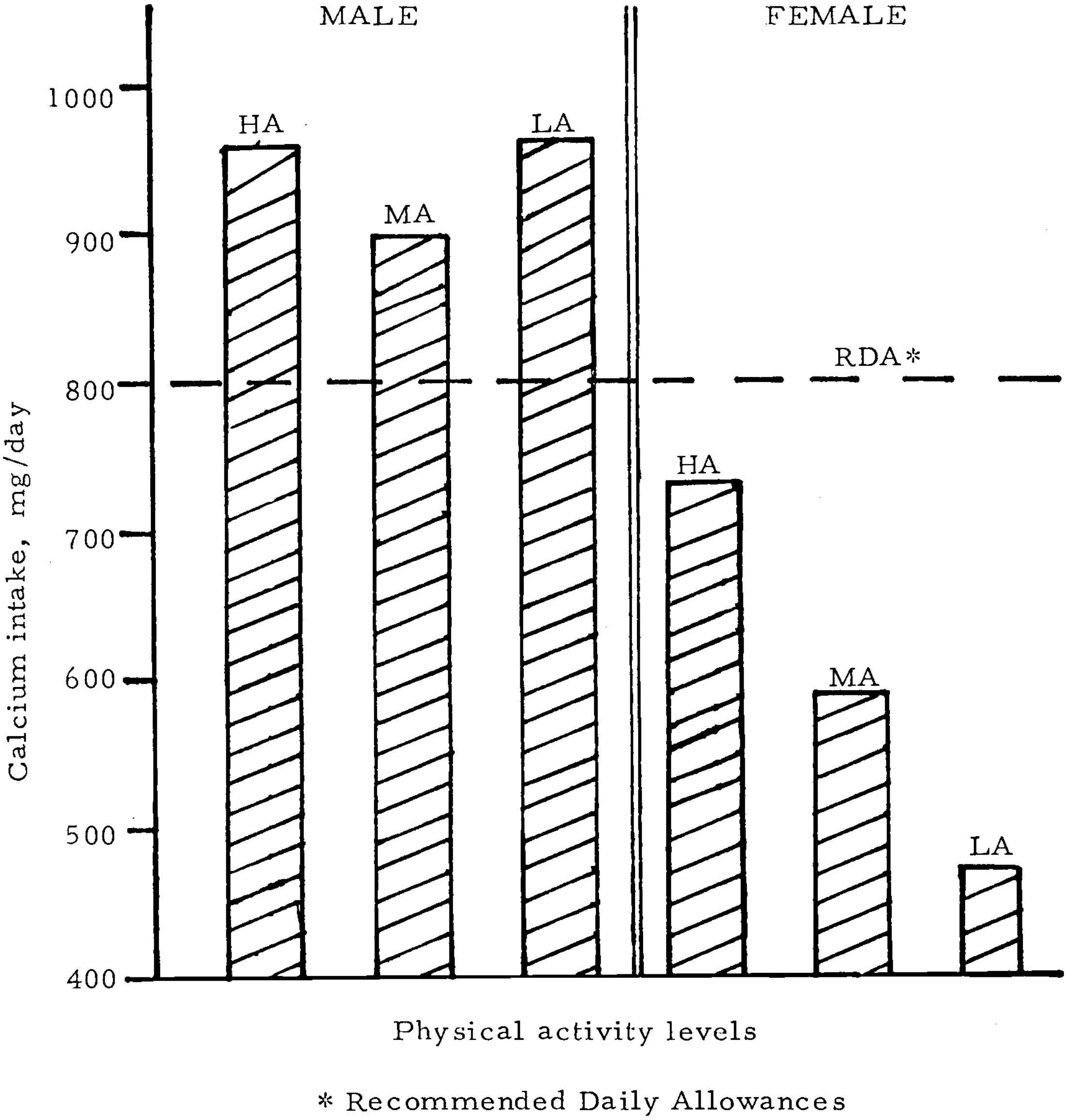

Figure 6. Mean calcium intake by physical activity levels and sex.

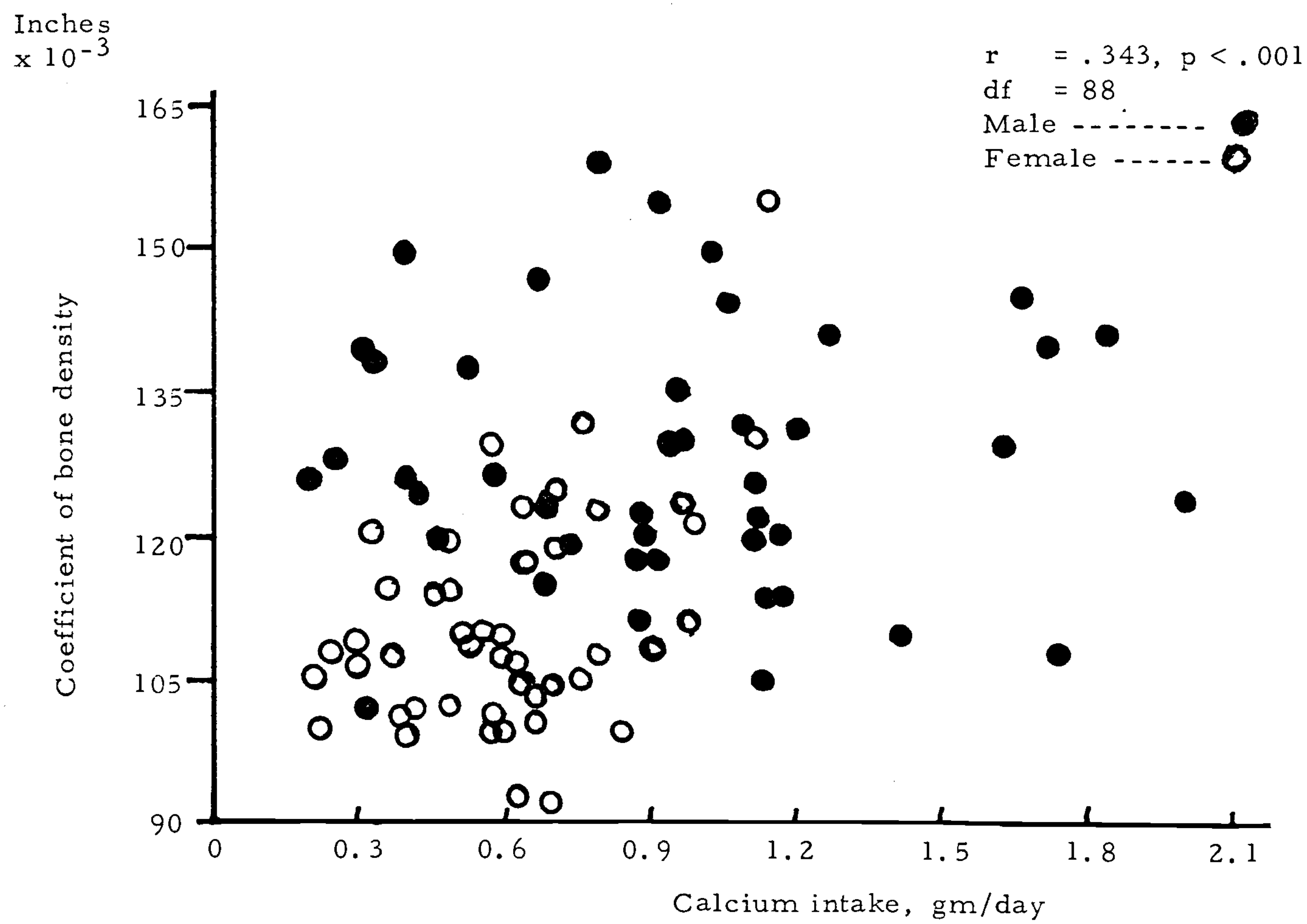

Figure 7. Relationship between calcium intake and bone density.

Discussion of the Findings

An analysis of the bone density scores indicated a significant difference in the bone density of the three physical activity levels. Males were also found to have significantly denser bones than females. This difference between the sexes is in line with the findings of Albanese and his co-workers (2). They found that after age 15, the density of phalanx 5-2 became significantly greater in the males than in the females. As shown by Table 3 and Figure 5, males in the current study had 16 percent denser bones than females. Although the means of 128.27 and 110.50 for the males and females respectively were greater than the average reported by Albanese (3) for ages 15-25 years, five of the subjects in this study showed evidence of subnormal bone density. This suggests that osteoporosis may not be limited to the aged. Sex differences in bone density was also reported by Nordin (55). Women's bone density reached its peak ten years earlier than men's. The rate of decline per decade is about ten percent of the initial mean value in women but somewhat less in men.

These sex differences make women more susceptible to osteoporosis than men and thus may account for the finding by Iskrant (42) that fractures of osteoporotic origin occur four times more frequently in women than in men. Greater impact of hormonal imbalance on post-menopausal female population than on their male counterparts, has been cited as a major reason for the significant difference between the bone density of aged males and aged females. However, existing literature on this subject does not identify hormonal imbalance as a major factor in the sudden difference between the bone density of adult males and females between the ages of 15 and 25 years. Some known physiological changes do take place in both sexes within these years that make for more prominent differentiation between males and females. But cultural standards, rather than physiological limitations, also make it possible for the male to participate in more physical activities than his female counterpart.

Perhaps more important than the difference between the sexes, is the significant difference found in the bone density of the physical activity levels. Although substantial controversy still exists over the effects of muscular activities on bone growth, virtually all the researchers (29, 37, 39, 89, 91, 96) agree that physical stress does improve the trabeculae structure, cortical thickness and density of the bone.

Deterioration in the bone resulting from immobilization can be detected much faster than measurable improvements resulting from a physical exercise program. Because of this, earlier studies on human bone density had been directed towards the effect of inactivity on bones. Several studies (8, 24, 38, 43, 47, 48, 94) reported that inactivity is a major cause of osteoporosis and that bed rest results in rapid calcium loss and significant decrease in bone density. The only positive report was a personal observation by Ross (71) of an increase in size and strength of the remaining phalanges and corresponding metacarpal of the hand of a laborer, 30 years after he had lost all the fingers of his right hand except the little finger.

The findings of this study present positive evidence as to the significant role of physical activity in developing and maintaining a dense bone. The highly active (HA) group was found to have significantly denser bones than both the moderate (MA) and low activity (LA) groups. This confirms the reports of the studies cited above, that muscular stress results in increased mineralization of the bone. As shown by Table 3, no significant difference was found between the bone density of the moderate (MA) and low activity (LA) groups ($p > .05$). The superior bone density of the highly active group and the insignificant difference between the less active groups (MA and LA) support the principle 'Specific Adaptation to Increased Demand' (S.A.I.D. Principle). The principle states that the human body is capable of restructuring its systems to cope with the physical stress they are called upon to bear. This stress, however, must be intensive enough to force the particular system to adapt.

This finding thus raises an important question. How much physical activity is required to maintain a strong, dense bone and how much is needed to achieve a significant increase in the density of an individual's bone? A complete answer to this question is beyond the scope of this study. However, the fact that the bone density of the moderate and the low activity groups did not differ significantly and the fact that their scores were comparable with the average bone density reported by Albanese (2, 3) for normal 'healthy' Americans of their age group, tends to suggest that all that is needed is an average active life to maintain a 'normal' bone density. A study by Whedon and Deitrick (94) disclosed that urinary calcium increased less rapidly during immobilization on a slowly oscillating Sanders bed. If this minimal movement can cause a reverse, no matter how small, in the disabilitating effect of immobilization, an average active life could help to ensure a normal 'healthy' bone.

The average bone desnity for various age groups and sexes reported by Albanese and his co-workers (2, 3), very valuable as they are, should not be considered desirable standards for physically fit individuals. The fact that even the least active group in this study had a higher bone density than the reported average, bears testimoney to this view.

One of the central questions requiring an answer then is, what is the minimum bone density necessary to withstand the stress and strain beyond that required for sedentary living? Therefore, there exists a critical need to establish standard norms on bone density such as there is for cardiovascular fitness. Establishment of such a norm would assist in determining scientifically the minimum and maximum level of physical activity and also the amount of calcium intake required to build and maintain strong 'healthy' bones.

Based upon the significantly denser bone found in the highly active group of this study, one can say that a more strenuous physical activity level is required to effect a bone density which will be substantially higher than that of the average population described by Albanese (2, 3). This finding is important too, in that it supports the theory proposed by Thoma (82) back in 1907. Although Thoma had been correctly criticized for the extreme mechanical view he held on bone formation, his theory on the growth in the thickness of the human bone is confirmed by the current study.

The low but significant positive correlation found between calcium intake and bone density in this study confirmed the significant role played by dietary calcium in the density of the bone. Calcium is regarded as the most important mineral that determines the strength of the bone. A low dietary calcium is, therefore, associated with esteoporosis. It seems that increased calcium intake together with regular physical activity will result in increased bone density.

A critical look at the scattergram of the correlation between calcium intake and bone density (Figure 7) suggests a possible sex difference in the pattern of the correlation. Were it not for the female scores crowning up in the bottom left corner, the correlation between calcium intake and bone density might not have been significant. Separate correlation of the scores of each sex in future studies would perhaps provide a clearer picture of the relationship between calcium intake and bone density.

As shown by Table 4, no significant difference was found in the average amount of calcium consumed per day by the three physical activity groups. This suggests that although calcium intake is very important, physical activity is perhaps the more dominant factor determining the density of the bone.

Males in this study consumed significantly more calcium per day than females. The males consumer 17.4 percent more calcium per day than the RDA, while the females consumed 33.4 percent less than the 800 mg. RDA! While 37.7 percent of males consumed less than 800 mg/day, 84.4 percent of the females in this study consumed less than 800 mg of calcium per day. This suggests that difference in calcium intake may be an important factor in the significant difference found between the bone density of the males and that of the females.

The results of this study have established the significance of muscular activity and nutrition in the development of dense, strong bones. Appositional growth and increase in the density of the bone occur in proportion to the compressional load the bone is asked to carry. Thus, a minimum level of physical activity above the sedentary level is needed to induce increased deposition of new bones and their calcification. In addition to increased calcium and vitamin D intake, we must consider scientifically prescribed physical activities as an essential prescription in the treatment and prevention of osteoporosis.

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Fractures, usually of the lower limb and hip associated with "bone fragility", now constitute one of the major disabling afflictions of the elderly and occur four times more frequently in women than in men. The reduction in the mass of bone known as osteoporosis has been closely associated with inactivity, immobilization and inadequate calcium intake. Bones, like muscles, become stronger as greater demands are made upon them. But increased inactivity resulting from increased industrial mechanization has led to noticable deterioration in the structures and functions of the various organs of the bodies of the modern-day men and women.

The primary purpose of this study was to determine the effects of various levels of physical activities and calcium intake on the density of the bones of 'healthy' young men and women. The relationship between sex and bone density was also tested by comparing the bone density of the males with that of the females.

Ninety 'healthy' male and female Oregon State University student volunteers, served as subjects. All subjects filled out a physical activity inventory and were administered a hand-grip test. The results of these tests were used to classify the subjects into three physical activity levels: Highly Active (HA) group, Moverately Active (MA) group, and Low or Minimally Active (LA) group. Fifteen subjects were randomly selected from each of the two sexes and the three physical activity levels for a total of ninety subjects.

In determining average daily calcium intake, each subject filled out a nutrition inventory in which they recorded all they ate and drank for three consecutive days. A week after the first record, subjects filled out another three consecutive days' record of their food intake. The quantitative radiographic technique described by Albanese and co-workers (2, 7) was used in determining the density of the subjects' bones. This is a radiographic measurement of the second phalangeal segment of the small finger (phalanx 5-2), of the right and left hands of each subject.

The two-way analysis of variance was computed to compare the scores of the physical activity levels and sexes, and the Pearson Product Moment Correlation Coefficient (Pearson 'r') was computed to test the relationship between calcium intake and bone density. The .05 level of conficence was used in retaining or rejecting each of the hypotheses tested.

Conclusions

Based on the results of the statistical analysis of the various scores, the following conclusions have been drawn from the findings of this study:

1. Prolonged regular physical activity has significant effects on the density of the bone. The highly active individuals have significantly denser bones than both the moderately active and the lowly active. There is, however, no significant difference between the bone density of the moderately active and the lowly active. This means that although physical activity causes an increase in bone density, the stress and strain on the bone must be of certain minimum magnitude before any substantial increase in bone density is manifested.
2. There is a significant difference between the bone density of males and that of females. Males have significantly denser bones than females.
3. There is no significant difference in the calcium intake of the three physical activity levels. It may be possible that the superior bone density found in the highly active group is directly related to the difference in

physical activity levels independent of any difference in calcium intake within the groups.

4. The males consume significantly more calcium per day than the females which most likely contributes to a low incidence of esteoporosis found in males.

5. A low, but significant positive correlation exists between calcium intake and bone density. Up to a certain optimum, and with a minimum amount of physical activity (yet to be determined), the higher the calcium intake, the denser the bones.

Recommendations

The findings of this study and the limited literature on the effects of various conditions on the bones of the human being suggest that with the technology now available, more research can and needs to be done directly on human beings as opposed to the indirect way of trying to relate findings in rats and dogs to the human body.

1. Current literature suggests that about seven-eights (7/8) of our calcium intake is lost through the feces and urine but physical activity tends to reduce this large excretion of calcium. There is, therefore, a need for more studies

to determine how much injested calcium can be retained through physical activity. This would help to determine whether increased RDA of calcium is justifiable or not.

2. The findings of this study suggest the need for further research to determine the magnitude of stress and strain required to effect significant increase in bone density.
3. Physiological effects of dieting as a means of weight reduction and the possible connection between this practice and the low calcium intake observed among the females in this study, requires further investigation.
4. Since different physical activities affect the body systems and structures differently, the specific effects of various athletic activities and exercises on bone density needs to be studied. This will permit us to prescribe the most effective exercises for osteoporotic and post-bedrest patients.
5. Because of the apparent difference in the bone desnity of races, cross-racial replications of this study will help to determine how universal or unique to the population under study, are some of the findings of this study.

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APPENDIX A

Lasun Emiola
'Bone Density Research'
c/o Physical Education Dept.
Oregon State University
Corvallis, OR 97331

Dear Student:

As part of my graduate studies, I am interested in determining the role physical activity and nutrition may play in the bone density of both male and female subjects between the ages of 20 and 25 years.

By volunteering as a subject for this study, you will be required to do three things. First, you will fill out a physical activity inventory, detailing the present and past physical activities which you have engaged in on a regular basis (at least twice a week) over an extended period of time. Secondly, submit to a bone density test, which involves taking an x-ray of the second phalanged segment of the small finger (referred to as phalanx 5-2) of your right and left hands. This test will be conducted with a dental x-ray machine, in the office of Dr. J. Bowman, 1799 NW Kings Boulevard. And thirdly, you will keep track of your food intake for two, three-day periods.

The whole testing will take less than an hour of your time, and you will have a choice of an arranged day and time. All information gathered shall remain anonymous and participants shall be referred to by their identification numbers only.

I should therefore be most grateful for your willingness to participate in this study. Please complete the part of the following form that applies to you and the consent form, then return them by campus mail or by hand to the address above.

APPENDIX

APPENDIX A

Name ________________________ Ref. No. ___________________
(for official use only)

Local Address ________________________ Phone ______________

Sex ______ Age ______ Height ______ft. ______in. Weight_____lbs

Would you be willing to participate in this study? __________

PHYSICAL ACTIVITY INVENTORY

A. COLLEGE/AMATEUR OR PROFESSIONAL ATHLETES.

1. Are you a current College, AAU or Professional Athlete?
____
2. If yes, in what sport(s)? ____________________________
3. For how long have you been competing? ________________
4. Do you participate in any out of season activities on a regular basis (minimum twice a week)? ________________
5. If yes to question 4:

Name of Activity	Frequency (Hrs/week)

B. FORMER ATHLETES

6. Did you participate in any highly competitive athletics (above intramural level)? __________________________
7. If yes, in what sport(s)? ___________________________
8. When did you stop competing? _______________________
9. Do you currently participate in any regular (minimum twice/week) strenuous physical activity? _______________
10. If yes to question 9:

Name of Activity	Frequency (Hrs/week)

C. INTRAMURAL & RECREATIONAL ATHLETES

11. Do you participate regularly (minimum twice/week) in any intramural competition or any vigorous individual physical activity? ______________________________

12. If yes to question 11:

Name of Activity	Frequency (hrs/week)

D. NON-ATHLETES

13. Do you participate in any regular (minimum twice/week) physical activity or heavy manual labor? ______________

14. If yes to question 13:

Name of Activity	Frequency (hrs/week)

E. ALL SUBJECTS

As a teenager, did you engage in any heavy physical manual labor on a regular basis?

Example: work on a farm or ranch.

Kind of work	Frequency (hrs/week)	No. of years

How will you rate your <u>Present</u> overall intensity of physical activity? (circle one)

Very High - High - Average - Low - Very Low

CONSENT FORM

In consideration of the benefits of this study to public health, the undersigned, a student at Oregon State University, agrees to participate in a research, "Effects of Various Intensities of Physical Activities and Nutrition on Human Bone Density, as Measured by Radiographic Technique," under the direction of John P. O'Shea, Ed. D., Holm Newmann, M. D., Ph. D., and Lasun Emiola, M.S.

The undersigned states that he/she is participating in this study voluntarily and consents to having the x-ray of the second-phalangeal segment of his/her small fingers taken; filling-out some questionnaires on his/her physical activities and eating habits, and to the use of the data to be generated therefrom as the above agencies may desire. He/she is free to withdraw from further participation, at any stage of the study.

______________________	______________________
Witness	Participant
______________________	______________________
Date	Date

Thank you very much for your cooperation. Subjects will be randomly selected and you will be notified if you are selected to take part. If you have any questions please feel free to call either Dr. Pat O'Shea - 754-2621 or Lasun Emiola - 754-3128.

Sincerely,

Lasun Emiola

APPENDIX B

NAME: ______________________________

Ref. No. ____________________

Age: _______ yrs. Weight: _________ lbs. Height ______ft. _____ins

Sex: Male ______ Female _______

INSTRUCTIONS

On each of the following three pages, please record your food intake for each of three consecutive days. Be specific as to kinds and amounts (i.e., "1 slice white bread toasted, plus 1 pat butter" instead of "toast").

Name ____________________

24 HOUR DIARY OF FOOD CONSUMED

Where eaten ________________ Date ____________________

Meal	Food	Amount	Description
Breakfast			
Lunch			
Dinner			
Between Meals			

Name ______________________

24 HOUR DIARY OF FOOD CONSUMED

Where eaten ______________ Date ______________________

Meal	Food	Amount	Description
Breakfast			
Lunch			
Dinner			
Between Meals			

Name ______________________________

24 HOUR DIARY OF FOOD CONSUMED

Where eaten ____________________ Date ______________________________

Meal	Food	Amount	Description
Breakfast			
Lunch			
Dinner			
Between Meals			