CHAPTER III

SURVEY OF LITERATURE

(b) EXPERIMENTS
The bone mineral content was determined by measuring the transmitted photon intensity from a radioactive source $^{125}$I (27.3 keV) or $^{241}$Am (59.6 keV) through the bone specimens using NaI(Tl) scintillation detector system for the first time by Cameron and Sorensen. This method has the following advantages:

1. The transmission of the photon beam is measured directly by counting techniques, by means of a scintillation detector system.
2. The photon beam used is essentially monochromatic.
3. The photon beam and detector are well collimated; and
4. The effects of the tissue around the bone are taken into account. Since the source and detector are well collimated, errors from the scattered radiation are reduced, the results are accurate and reproducible within 2-3 percent.

Weber and Van den Berge have determined experimentally the effective atomic number of compounds. An empirical relation for the cross section of the photoelectric effect per atom was given by Walter. Spiers has given an expression for mass attenuation coefficient for compounds. Weber and Van den Berge have shown that the values obtained for photoelectric cross section using the empirical relation given by Walter are different from those tabulated by Grodstein. The exponent of the atomic number for the photoelectric cross section has been changed from 2.94 to 3.4.
or higher values. The coherent scattering is less dependent on the atomic number and is proportional to \( Z^{1.7} \) Using these modified empirical relations they have determined the mass attenuation coefficients of water and water equivalent materials and they have found that the modified empirical relation suggested by them is more accurate.

West and Reed\(^6\) have developed an apparatus to measure the transmission of a beam of 60 keV \( \gamma \)-radiation from Am\(^{241}\) and scanned the selected sites in a number of patients. They have observed that the bone loss increases with age and is greater in women than men, the effective bone density and cortical bone density indicate age and sex differences. Atkinson and Weatherell\(^7\) have shown that the density loss with age is greater in the anterior than in the posterior. This has been confirmed by West and Reed\(^6\) from their measurements on normal subjects. Linear attenuation coefficient measurements have shown the muscle/fat ratio within the soft tissue at the lower end of thigh is also both age and sex dependent. They have reported that their results are reproducible within 2 percent.

Farmer and Collins\(^8\) have described the method of determining the anatomical cross-section of the body by Compton scattering using gamma rays from \(^{137}\)Cs source. They have discussed various corrections to be applied.
Garnett, Kennett, Kenyon and Webber have described a technique for the determination of absolute bone density in man using Compton scattering method. They have calculated that the scattering technique does not suffer from the disadvantages inherent in transmission techniques. That is, it is independent of soft tissue attenuation and bone density is measured directly in units gm/cm$^3$. The results of density of hemivertebrae are in good agreement with those obtained by Archimedes' principle. So they conclude that the dose delivered to the patient during the measurement can be reduced significantly if a low energy photon source is used. Their results for in vivo measurements of absolute bone density are reproducible within 2 percent.

Piper and Preuss have determined the absolute bone density using $^{153}$Gd (100 keV) and $^{170}$Tm (84 keV) Compton scattered photons from trabecular bone from distal tibia of cattle and have obtained the densities between 1.13 gm/cm$^3$ and 1.58 gm/cm$^3$.

Olkkonen and Karjalainen have determined the absolute bone density by measuring both transmitted and scattered photons from a 650 mCi $^{170}$Tm source. In a narrow beam geometry, this method takes into account the change in the effective Z/A as a function of bone density which leads to change of elemental composition of bone, when bone mineral is
resorbed They have determined the bone density for 24 bone specimens by this method and have a good correlation (r=0.94) with the results obtained from the Archimedes' principle.

Webber\textsuperscript{12} has measured os calcis density using $^{153}$Sm (103.2 keV) as a function of body weight for 52 normal volunteers and has found good correlation (r=0.74) between os calcis density and body weight. Further he has studied 16 patients having radiological evidence of Osteoporosis and found that the density is less than the predicted value from their body weight for each patient.

Olkkonen and Puumalainen, Karjalainen and Alhava\textsuperscript{13} have measured the bone mineral density by taking the ratio of coherent to Compton scattered photons from $^{241}$Am source (45 mCi) using germanium semiconductor detector with multichannel analyser. They have suggested a linear regression formula which relates bone mineral density and $A_{coh}/A_{comp}$ ratio.

Webber and Kennett\textsuperscript{14} have measured the os calcis density of 12 human subjects in the age group of 24-49 years as a function of body weight using $^{153}$Sm (103.2 keV) and $^{170}$Tm (84 keV) sources and two sets of detectors. The os calcis density of above subjects has been found to vary between 1.11 gm/cm$^3$ and 1.53 gm/cm$^3$. Further Kennett and Webber\textsuperscript{15}...
investigated the origins of inherent sources of error in results of the measurement of the density by photon scattering technique.

Puumalainen, Uimarihuta, Alhava and Olkkonen\textsuperscript{16} have measured the bone mineral density based on the detection of both coherent and Compton scattered photons in a narrow beam geometry using \(^{241}\text{Am}\) source and intrinsic germanium semiconductor detector with an accuracy of 2 percent for the calcium-hydroxy-apatite content of sample and cancellous bone samples.

The coherent-Compton scattering method was used for the measurement of the fat content of liver in autopsy specimens of normal subjects and cases with different diffuse liver diseases by Puumalainen, Olkkonen and Sikanen\textsuperscript{17}. The results of the photon scattering method correlated closely with the chemically analysed fat content. Elicited fat content in cases with fatty liver disease and stasis has been separated from normals by the scattering method.

Huddleston and Bhaduri\textsuperscript{18} have studied the effects of multiple scattering on density of femoral bones using single source low-energy Compton densitometer. They have determined the relative electron density and mass density using samples of known density and also samples of human...
cancellous bone tissues. They have observed that the measured values strongly depend on the diameter (geometry) and density of the samples. They have evaluated the multiple scattering and attenuation in human femoral bones and have suggested a correction for such effects.

Huddleston, Bhaduri and Weaver\textsuperscript{19} have determined the physical density by Compton scattering densitometry. The measured values depend on the geometry used for the measured diameter of the sample, the density and the scattering volume size and shape influence the relative electron density values obtained by such system. They have defined bias in the computed Compton density, due to multiple scattering and attenuation, and an expression is given relating the density bias to the geometrical parameters. The importance applying corrections to the computed physical density for samples of large diameter and high density has been discussed for various bone tissues.

Stalp and Mazess\textsuperscript{20} have determined the bone density by counting the number of Compton and coherently scattered photons using the incident radiation from \textsuperscript{241}Am source and a Germanium solid state detector. They have improved this technique by using more optimal scattering angles and higher incident beam energy. This is clinically more attractive, that is, (a) sensitivity to changes in both bone density and
elemental composition, (b) eliminates attenuation corrections for overlaying structure and (c) the ability to measure the axial skeleton. They have used $^{241}$Am and $^{153}$Gd source to measure the Compton to coherent ratio and density of the phantoms.

Dunn, Wahner and Riggs\textsuperscript{21} have measured the bone mineral content in the axial skeletons using a dual-probe scanner with PDP-11 computer, $^{153}$Gd sources and a NaI(Tl) detector. The results have been found to be accurate and reproducible and distinction of osteoporotic women from normal age-matched women has been reported to be superior to that accomplished with single photon absorptiometry in the radius.

White and Tucker\textsuperscript{22} have discussed the problems inherent in the design and manufacture of mammographic test objects and a test object is described which may be used for assessing image quality. Some typical results from both good and bad mammographic machine/film combinations have been presented.

Gupta and Nilekani\textsuperscript{23} have used the tissue equivalent FBX dosimeter for studies of a plane $^{90}$Sr-$^{90}$Y medical applicator. The dose to a thin dosimeter increases 5 times due to perspex backscatter, further increase in the backscatter with increase in the atomic number is small. They
have shown that the backscatter factor depends on the thickness of the dosimeter. The dose at different depth of the tissue has been shown to fall almost linearly. Electrons scatter greatly influences the dose distribution.

Rustgi, Siegel, Braunstein, Craven and Greenfield\textsuperscript{24} have tested the liability of the data obtained from the commercially available Norland-Cameron bone mineral analyzer. The bone mineral content values have been found to be higher from those determined by direct measurement.

Differential changes in bone mineral density of appendicular and axial skeleton with the age is investigated by Riggs, Wahner, Dunn, Mazess, Offord and Melton\textsuperscript{25}. They have observed overall bone diminution throughout life is about 47 percent for the vertebrae, 30 percent for the mid radius and 31 percent for distal radius. In normal men vertebral and appendicular bone diminution with aging was minimal or insignificant. Mean bone mineral density has been observed to be lower in patients with osteoporosis than in age-and sex-matched normal subjects at all 3 scanning sides. Their data suggests that the disproportionate loss of trabecular bone from the axial skeleton is a distinguishing characteristic of spinal osteoporosis.

The density of trabecular bone in the os calcis has been
measured in 321 subjects by Roberts, DiTomasso and Webber\textsuperscript{26} using a gamma ray scattering technique. They have observed that the density could be predicted from the body weight and age with standard error of 5-6 percent in the normal subjects. They have shown that the dependence of density/weight and age was same for both sexes. When os calcis had been subjected to a greater than normal mechanical stress by either increased physical activity or excessive body weight, trabecular bone density was increased. They have measured the density in 128 patients in whom the incidence of skeleton demineralization was expected to be greater than in control subjects and have observed some significant reduction in density. It is projected that the density measurement where in response to metabolic stress, the rate of loss mineral from trabecular bone is greater than that from cortical bone.

The trabecular bone mineral density in vitro is determined by Ling, Rustgi, Karellas, Craven, Whiting, Greenfield and Stern\textsuperscript{27} by measuring the ratio coherent to Compton at $90^\circ$, 60 kev photons from a $^{241}$Am source by using a narrow beam geometry and intrinsic Germainium detector. The feasibility of using smaller scattering angles for better counting efficiency and the measurement have been studied. They have observed the linear relationship between the coherent to Compton ratio $R$ of the detected counts TBMD with
fresh trabecular bone samples. The effect of self-attenuation by trabecular bone itself and cortical layer was negligible. They have found that the marrow content could alter the value of R ratio. A 10 percent increase in fat content in the interstices of the trabecular bone a 2.5 percent decrease in the R ratio was observed. This technique together with soft tissue corrections will enable one to measure the TBMD of the calcaneum in vivo.

The noninvasive dual energy Compton technique which incorporates the determination of effective attenuation coefficients for various substances is described by Huddleston and Weaver. The theoretical considerations of dual energy Compton scattering are presented, and calculated the electron density of various materials of known compositions, using $^{153}$Gd source which provides two photon energies and NaI detector. They have measured the Compton scattered photons at 90° for various materials and determined the electron density. These results have been compared with those values of electron density calculated from dual energy Compton scattering and the results agree within 2-3 percent.

The measurement of the coherent and Compton scatter photons from a material can provide information about its composition. The ratio of coherent to Compton scattering R can be used to determine mineral density. The coherent
scattering depends on the effective atomic number ($Z$) of the scattering material and at small scattering angles, Karellas, Leichter, Craven and Greenfield\textsuperscript{29} have increased the scattering angle and have found stronger power dependence of the measured ratio on $Z$. It is obvious that by increasing the scatter angle, smaller changes in the mineral density can be detected which improves the sensitivity of the measurement. This has been investigated experimentally by Karellas\textsuperscript{29} et al. by using a collimated beam 60 keV photons from $^{241}$Am source and an intrinsic Germanium detector.

A comparison between the $^{153}$Gd and $^{241}$Am, $^{137}$Cs for dual-photon absorptiometry of the spine has been done by Smith, Sutton and Tothill\textsuperscript{30} by determining the bone mineral content (BMC) of the spine from the attenuation measurements of two photon beams. They have suggested an equation for the precision evaluation of BMC and have showed its validity from the experiments. They have observed that though $^{153}$Gd was found to possess the better energy combination, the precision due to the photon energy levels using $^{241}$Am, $^{137}$Cs was only 1.5 times the value obtained from $^{153}$Gd. The available photon outputs from $^{241}$Am and $^{153}$Gd were investigated and with a 12 mm diameter disc source a theoretical precision of 1 percent could be obtained with source strengths 20 GBq $^{241}$Am or 5 GBq $^{153}$Gd in a 40 minute and 20 minute patient scan respectively. There was no great advantage in either energy
When the problems of fat or patient dose were considered, given the disadvantages of $^{153}$Gd, its cost and availability, $^{241}$Am, $^{153}$Cs can be used as a practical alternative to measure spine BMC from a reconstructed bone mineral image.

Sabatier, Heron, Petiot, Bouvard, Dallet, Lefevre and Ledard have presented an apparatus for measuring bone mineral content of lumbar spine, using a dual photon absorptiometry technique.

Roberts, Lien, Woolever and Webber have determined density of calcaneal trabecular bone in normal postmenopausal women and in patients treated for osteoporosis. Cross-sectional measurements of density were made in previously normal patients who had been without ovarian function for a known length of time. They have observed a significant reduction in calcaneal density associated with aging in normal postmenopausal women. They have also observed that the estrogen lack was associated with density reductions and the reduction was related to the length of time of estrogen deprivation. When osteoporotic patients were treated with combination therapy, density rose in females while in males the expected age-dependent reduction was prevented. They have concluded that the photon scattering measurements of calcaneal density can be used to monitor changes in the...
mineral status of the skeleton

The effect of the momentum transfer on the sensitivity of a photon scattering method for the characterization of tissues has been investigated by Leichter, Karellas, Craven and Greenfield. The ratio of coherent to Compton photons scattered by a tissue-like material depends on its effective atomic number. This ratio can be used for the in vivo characterization of tissues. The sensitivity depends on an angle and the photon energy. The dependence of the sensitivity on the energy of the incident photons has been investigated in two ways by them: (1) Quasitheoretical, is based on the computation of cross-sections of coherent to Compton scattering for various energies, and (2) measurement of the scatter ratio from a series of K$_2$HPO$_4$ solutions for 60, 81 and 140 keV photon energies. The combined effect of both the photon energy and scattering angle on the sensitivity is described by a single parameter which is the momentum transfer. They have concluded that for the limited range of the atomic numbers which apply to trabecular bone the momentum transfer reflects completely the effect of the scatter angle and photon energy on the sensitivity.

Nageswar Rao, Perumallu and Krishna Rao have measured the photon attenuation coefficients at seven energies in the range 30-660 keV for 18 elements and 29 compounds
using a NaI(Tl) detector in a narrow beam geometry. They have obtained total photon cross sections for certain elements applying mixture rule. Atomic photo effect cross-sections in medium and high Z elements in the energy range 30-280 keV are derived from all data by substituting the relatively small scattering (coherent + incoherent) cross-sections from the total atomic cross-sections. They have compared these results with theoretical values.

Thirumala Rao, Raju, Narasimham, Parthasaradhi and Mallikarjun Rao have investigated the interaction of low energy photons with biological materials and deduced the effective atomic number. They have determined the effective atomic numbers for total photon interaction in bone, muscle, liver, spleen, fat and water and they have found this to decrease up to 50 per cent as the energy increases from 10 keV to 200 keV. They observe that muscle, spleen, liver, and water are found to behave in an approximately similar manner in this energy range as far as photon interactions are concerned.

The Z-dependence of photon cross-sections and the variation of Z-exponents with energy and elemental compositions have been studied by Perumallu, Nageswara Rao and Krishna Rao with an emphasis on substitute materials of
biological importance The validity of the evaluated Z-exponents and effective atomic numbers has been tested by means of the measured attenuation coefficients in compounds and stimulated materials in the energy range 30-150 keV. They have suggested an empirical relation for the mass attenuation coefficient to characterise a phantom material.

Quantitative investigation of bone mineralization has been done by Sabatier, Guaydier-Souquieres, Courtheoux, Rivaton and Loyau using the technique of biphotonic absorptiometry. The study of a control and an osteoporotic population allowed the definition of the fracture threshold independent of age and the curve of the variation in the mineral content with aging. They have observed good correlation with computed tomography (CT). They conclude that the biphotonic absorptiometry is an excellent examination for the detection of demineralization and for the monitoring of treated subjects.

Dual photon absorptiometry with $^{153}$Gd was used to measure the mineral content of lumbar vertebrae in cadavers, excised vertebrae with marrow, and dry, marrow free vertebrae by Wahner, Dunn, Mazess, Towsley, Lindsay, Markhard, and Dempster. They have concluded that the DPA accurately indicates bone mass and bone density, and is only slightly affected by either surrounding tissue or changes in bone.
Bone mineral density of the calcaneum has been measured by Shukla, Karellas, Leichter, Craven and Greenfield\textsuperscript{39} using photon scattering method. In this method calcaneum was irradiated by a 60-keV photon beam from \textsuperscript{241}Am and coherent and Compton scattered photons were measured by a high purity Germanium detector. The bone mineral density is determined by measuring the ratio of coherent-to-Compton scattered photons. This was compared with directly measured bone mineral density by Archimedes' volume displacement method. The precision was determined to be 3 per cent.

Trabecular bone mineral density was measured in vivo in the calcaneus by a method that uses the ratio of coherent to Compton scattered photons by Shukla, Leichter, Karellas, Craven and Greenfield\textsuperscript{40}. The coherent to Compton scattered photons arising from radiation of a small volume of trabecular bone by a gamma source [\textsuperscript{241}Am, (59.5 keV)] with highly collimated geometry. The measured values of trabecular bone mineral density for healthy men (22-77 years) were in the range 180-357 mg/ml and for healthy women (18-73 years) were 160-321 mg/ml. Further they have measured the trabecular bone mineral density of right and left calcanei of healthy subjects at a scattering angle 45\(^\circ\).
Huddleston, Posteraro, Sackler and Dunn\textsuperscript{41} have determined the electron density utilizing the measurement of Compton-scatter intensities at selected scattering angles and are influenced by the presence of multiple scattering of photons. The fractions of single scatter and multiple scatter have been assessed in samples of varying diameters using three different measuring geometries. The ratio of multiple-to-single scatter are given, and related to the measuring geometry and scattering angle. The implications of this for non invasive in vivo densitometry have been discussed.

Dual photon absorptiometry studies were performed to study the symmetry of hip bone mineral density by Lessig, Meltzer and Siegel\textsuperscript{42}, on the hips of 23 patients to determine whether bone mineral density values obtained from one hip were identical of the values in the contralateral hip of the ambulatory patients. The femoral neck, trochanteric, and Ward’s triangle areas of both the hips were analysed. They have concluded that there is no significant difference between right and left hip bone mineral density measurements. Any one of the hip may be used to evaluate osseous status.

The effect of multiple scattering in dual energy Compton-scatter densitometry for the measurement of electron density of bone and other tissues is discussed by Huddleston,
Sackler and Dunn\textsuperscript{43} They have determined the electron densities of known compositions using \textsuperscript{192}Ir (317 and 468 2 keV) source having an activity of 111 0 GBq. The air cavity method has been used to evaluate the multiple scatter fractions and the single scatter fractions over the range of scattering angles 20° - 90°, in cylindrical samples of diameter 3.5-6.5 cm. They have concluded that the corrections for the effects of multiple scattering are essential for improving the sensitivity, accuracy and precision of dual energy Compton-scatter densitometry.

Measurement of soft tissue and bone density in g/cm\textsuperscript{3} have been made by Henson\textsuperscript{44} using 80 kV and 140 kV dual energy CT scanning. Comparison of values measured by CT using a water phantom give agreement within 1 per cent for samples of known density. Results from both a cadaver leg and a patient's leg gave mean difference of 0.6 per cent from those predicted from calculations using published data. His results indicate that a scanner can be calibrated for single energy measurements of density by using three materials to cover the range from fat to cortical bone.

Dual photon absorptiometry was performed to determine and compare bone mineral density of the both hips by Balseiro, Fahey, Ziessman and Le\textsuperscript{45} They have determined the bone mineral density of both hips of 40 patients.
compared the bone mineral density of both hips, Ward's triangle, femoral neck and greater trochanter. They have concluded that the absolute error of predicting one hip from the other was not a function of bone mineral density (BMD) and, thus, the relative error increases with lower bone mineral density (BMD) values.

Bone density was measured in the proximal femur, lumbar spine and distal radius in 423 ambulatory women, using dual photon absorptiometry by Mazess, Barden, Ettinger and Shultz. Femoral and spinal measurements at the standard 33 percent radius shift site were made using $^{125}$I single photon absorptiometry. There were 324 older women with no fractures, of which 278 aged 60 to 80 years served as age-matched controls. There were 99 women with hip fractures including 32 vertebral and 22 with hip fractures. It is concluded that the patients with spinal fractures had lower (10% to 15%) densities at all sites to age-matched controls. The preferential spinal osteopenia usually seen in younger patients with multiple crush fractures was not evident.

Computer simulations were performed to predict the performance characteristics of dual-energy X-ray absorptiometry by Sorenson, Duke and Smith. K-edge filter techniques were analysed in detail and compared to $^{153}$Gd source in terms of output intensity, precision, patient dose,
image contrast, beam hardening and marrow fat effects. They have concluded that the K-edge filter techniques, or a dual-KV technique combined with K-edge filtering, can provide performance capabilities that equal or exceed those achievable with $^{153}$Gd systems.

Henson\textsuperscript{48} has determined the electron density, mass density and calcium fraction by mass of soft and osseous tissues by dual energy computed tomography. The method uses six major elements, H, C, N, O, P and Ca as compartments for the analysis and can also be applied to soft tissue by using only the first four. The calculated mass fraction of Ca is found to be sensitive to fat content and difference between surface and internal energies which can lead to serious underestimates below a fraction of about 0.04. He has concluded that the mass and electron density results are independent of fat content and only marginally affected by energy difference.

Mazess, Barden, Vetter and Ettinger\textsuperscript{49} have discussed the advantages and disadvantages of SPA, DPA and QCT.

Sabatier and Guaydier-Souquieres\textsuperscript{50} have discussed the advantages and disadvantages of various non-invasive methods, SPA, QCT and (DPA and DEXA) to measure the bone mass and also evaluated the radiation exposure of patients to radiations.
Sabatier, Guaydier-Souquieres and Loyau\textsuperscript{51} have investigated the osteoporosis in Lower Normandy in 386 women who had undergone menopause or an ovariectomy, with ages ranging between 40 and 56 years. They have concluded that the percentage of high risk patients increases with the number of years since menopause. It is hoped that the incidence of osteoporosis will decrease with early screening and preventive therapeutic measures.

Using Gd-DPA, Sabatier, Guaydier-Souquieres and Bouvard\textsuperscript{52} have compared the bone mineral densities (BMD) of the lumbar spine and both femoral necks. Out of the 252 women they have studied: 110 were normal subjects, 98 were considered as high risk subjects and 44 were osteoporotic patients with one or more atraumatic vertebral crush fracture group.
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