REVIEW ARTICLE

Bone Densitometry

J. L. Bassi, Rajneesh Garg, Arvind Mohan

Introduction

During the last 25 years there has been increasing interest within the Orthopaedic community in the non-invasive measurement of the bone mineral content of various regions of the skeleton. The past decade has become an era which recognized bone denistometry at axial skeletal sites (spine and proximal femur) and offered improved diagnostic sensitivity in relation to osteoporotic fractures at these sites (1-3). These axial sites in addition to diagnosis are improtant for monitoring both the disease process itself and response to therapy. Bone changes occur early at these sites and are of greater magnitude than those in the appendicular skeleton. Osteopenia of menopause both natural and artificial is twice as great in the spine as the appendicular skeleton (5-6). The therapeutic effects of treating osteoporosis, renal osteodystrophy and corticosteroid excess are invariable more evident in axial skeleton (7-9). In some cases, fluoride therapy for osteoporosis was used and effects were mainly seen in the axial skeleton (11,12). These factors have led to clinical utilization of several methods for axial denistometry (13).

In general, densitometry techniques can be performed in either the axial or the appendicular skeleton. Peripheral measurements performed in the appendicular skeleton help to predict the risk of fracture. However, they are less sensitive for monitoring of therapy than are measurements in the axial skeleton because changes due to age, therapeutic intervention and estrogen deficiency occur less rapidly in the appendicular bone than they do in the axial skeleton (14,15).

Conventional radiographs will show a reduction in bone calcium content only when it exceeds 30% (16). Bone densitometry has a wide range of uses in modern day orthopaedic practice as it can detect the changes in the bone mineral density at much lower levels as compared to conventional radiographs and helps to diagnose and treat so called bone loss syndromes like osteoporosis (17). It is also used to evaluate periprosthetic bone remodelling after total hip arthroplasty (15).

Osteoporosis with its fallouts in the form of fractures is sweeping across the globe. The prevalence and risk of fractures increases dramatically with decreasing density (18,19). Each decrease of 10% or about 1 SD (standard deviation) in bone density of appendicular sites increases the relative risk of fracture about two fold. (fractures include hip fractures, colles fractures, spine fractures etc.).

Various methods of doing bone densitometry are :

(a) Radiographic absorptiometry
(b) Single X-ray absorptiometry
(c) Dual X-ray absorptiometry
(d) Quantitative computed tomography
(e) Quantitative ultrasonography

Principles of Bone Densitometry

Unit of measurement for bone densitometry is bone mineral content, expressed in grams. With different modalities of bone densitometry different instruments are used, but all record the attenuation of a beam of energy as it passes through bone and soft tissues.

From the Department of Orthopaedics, Dayanand medical College & Hospital, Ludhiana, Punjab, India.
Correspondence to : Dr. J. L. Bassi, 914/5, Tagore Nagar A, Deaf & Dumb School Road, Behind Tagore Hospital, Ludhiana (Pb) India.

Quantitative computed tomography is the only modality that allows the direct measurement of volumetric density expressed as grams per cm^3 (14). With other modalities bone mineral density is expressed as grams per cm^2 by dividing bone mineral content with the area that is scanned (20). These measurements are strictly skeletal site specific, thus individuals can be compared only when identical locations are studied.

Radiographic Absorptiometry

Radiographic absorptiometry is a technique for measuring radiographic density most commonly of the hand or the heel. The hand is positioned adjacent to an aluminum reference wedge and direct exposure settings are used to make a single radiograph at different radiographic energies. The mean density of middle phalanges of 2nd, 3rd and 4th fingers is calculated by mailing the radiograph to central reading facility, where the image is captured electronically with use of high resolution video camera.

Advantages of radiographic absoptiometry :

(i) Low Cost

(ii) Does not require specialized equipment.

(iii) Its correlation with bone mineral content determination with dual X-ray energy absorptiometry and correlation with ash weight of bones is good.

Disadvantages :

(i) Measurements are sensitive to changes in overlying tissues.

(ii) Technique is limited to appendicular skeleton.

Single Energy X-ray Absorptiometry

It is a technique for measuring the bone mineral content of appendicular skeleton usually the distal aspect of radius or calcaneus (15).

A collimated photon beam is directed from x-ray source, through the measurement site. The photon attenuation of the beam by bone is measured and converted to bone mineral content with use of a known standard.

Advantages : (i) Simple to use.

(ii) Comparatively low radiation exposure.

(iii) It has replaced single photon absorptiometry which used photon source and emitted much more radiation.

Disadvantage :

(i) Restricted to appendicular skeleton.

Dual Energy X-ray Absorptiometry (DEXA)

Introduced in 1987, is currently the most widely used modality for clinical measurement of bone mineral content (23). Single X-ray and single photon absorptiometry with dual photon absorptiometry has been replaced by DEXA. X-ray tube used in DEXA has replaced the radionucleotide source used in DEPA. DEXA compared with DEPA requires–

(i) Less time for examination.

(ii) More reproducible.

(iii) Less exposure to radiation.

With this technique the X-ray tube emits a x-ray beam the attenuation of which is detected by an energy discriminating photon counter. The x-rays are generated by energy switching system or by filtered x-ray system producing different effective energies that are emitted simultaneously. In this method, by using pair of energies, accurate results are attained independently of soft tissue thickness and to a large extent of tissue composition (24).

Major advantages with x-ray source compared with radioisotope is greater intensity, which greatly improves precision and accuracy. The photon flux produced by a x-ray source with mean tube current of 1 milli ampere is 500 to 1000 times greater than that produced by one curie gandolinium 153 source used in DEPA.

DEXA provides bone mineral measurements both axially and peripherally as well as total body scans.

- Scan of spine is performed in 1 minute.
- Scan of femur is performed in 2 minutes.
- Scan of whole body is performed in 4 minutes.

Radiation exposure is just 0.5 to 5 microsieverts. There is no need to shield either the patient or persons operating the equipment (25).

Advantages :

Detects small changes in bone mineral contents at multiple anatomical sites with less exposure to radiation, short examination time and excellent precision, making it a method of choice in determining bone mineral density (26,27).

Disadvantages :

Does not enable the examiner to differentiate between cortical and trabecular bone.

Quantitative Computed Tomography

This technique involves the use of a mineral callibration phantom in conjunction with a computed tomography scanner to measure bone mineral content or density. Vertebral body is the usual site of measurement. The phantom (which is a reference source used to calibrate measurements of bone density) usually consists of hydroxyapatite (bone ash) in plastic that is scanned simultaneously with the vertebrae. A lateral computed tomogram localizes the mid plane of two, three or four lumbar vertebral bodies and quantitative readings are obtained from a region of trabecular bone in the anterior portion of the vertebrae. The vertebral bone density determined by computed tomography is compared with known density readings of solutions in the phantoms. The measurements of vertebrae are averaged and commercially available software package is used to convert Hounsfield units to bone mineral equivalents.

A Hounsfield unit is a measure of x-ray attenuation for computed tomography scans in which each pixel is assigned a value on a scale with air equivalent to –1000, water to 0 and compact bone to +1000 (28).

Quantitative computed tomography has several theoretical and practical advantages compared with other techniques for the evaluation of bone mineral content :

(i) It is the only method that allows separate assessment of trabecular and cortical bone areas (29).

(ii) It is the only modality the allows the direct measurement of a volume of bone. This gives an accurate measure of three dimensional geometry of bone (15).

Disadvantage :

(i) Exposes the patient to higher dose of radiation. The dose of radiation with modern quantitative computed tomography has been reported to be approximately 29 microseiverts.

Computed tomography has been extended to study of appendicular skeleton especially distal end radius with the use of a special computed tomography unit with a small circular gantry. This method delivers a low dose of radiation. The dose of radiation associated with this procedure is 0.4 microseivert (30,31). Region of interest with computed tomography is L_2-L_4 area as L_5 is affected by arthritic changes and pathological changes are more in L_1 and L_5 vertebrae. L_1 is often subjected to fractures and is much lower in BMD than L_2-L_4.

Quantitative Ultrasonography

It is mainly a screening test for osteopororsis and is based on velocity and attenuation of ultrasound wave as determined by a pair of coaxially aligned transducers. An ultrasound signal generated by one transducer is sent through the bone and second (receiver) transducer detects the ultrasound wave as it emerges from the bone. This technology assumes that bones with different biomechanical properties have different ultrasound determined values for attenuation and velocity (32). Propagation of ultrasound wave in bone is affected by bone mass, bone architecture and direction of loading.

Advantages :

(i) It involves no radiation.

(ii) Relatively simple to implement and process is portable and inexpensive.

(iii) In addition to bone mineral content can measure additional properties of bone such as mechanical integrity (32). Sites most accessible for ultrasound are calcaneus, patella and to lesser extent radius, tibia and phalanges.

Clinical Indications for the use of bone densitometry

The various indications for use of bone densitometry :

(i) Estrogen deficiency in women at clinical risk of osteoporosis.

(ii) Patients with evidence of vertebral abnormalities.
(iii) Patients on long term glucocorticoid therapy.
(iv) Diagnosis of primary hyperparathyroidism.
(v) Need for monitoring the response or efficacy of an approved drug therapy for the treatment of osteoporosis.

Use of Bone Densitometry in Osteoporosis

Measurements provided by bone densitometry are important for assessing bone strength and corresponding risk of fractures. Fracture of proximal aspect of femur is most serious consequence of osteoporosis. It is most common with advancing age and female sex. This fracture is associated with devastating medical and economic impacts and one out of every six females in United States sustains this fracture and 20% die as a result (33).

Bone densitometry is used for identifying individuals with risk of osteoporosis, to study the effect of antiosteoporotic treatment in patients and asessing the need of enhancing existing bone mass where internal fixation is contemplated (15,34).

Interpretation of Bone Densitometry Report

A standard bone mineral report consists of measurement expressed as bone mineral content. In order to interpret a bone mineral report, region of interest must be selected. In order to compare individuals, the site of measurement should be constant because the bone mineral content may vary between different bones and between different regions of the same bone. Both a Z-score and T score are determined for each record to help in analyzing the results.

Z Score

The Z score is used to compare the patients bone mineral density with mean value of individuals of the same age. A low Z score indicates an etiology other than age related bone loss. The Z score is calculated by subtracting the patients result from the mean value for age matched controls and dividing this value by the standard deviation of the mean. Therefore by definition, Z score is zero at the mean value for the population. The Z score is expressed as a standard deviation.

T Score

T score is used to compare the patients bone mineral density with the mean value for young adults of the same gender and race. Like Z score it is also expressed as a standard deviation. The T score is used for diagnosis of low bone mass or osteoporosis. WHO has laid down guidelines for interpretation of bone densitometry reports (35).

Normal Value

Bone mineral content is within one standard deviation of the mean value for young adults of the same age and gender (T score more than -1).

Osteopenia

It is considered to be present when the value for bone mineral content is more than one standard deviation but not more than 2.5 standard deviations below the mean for young adults (T score is less than -1 and more than -2.5).

Osteoporosis

It is considered to be present when the value is more than 2.5 standard deviations below the mean bone mineral content for young adults (T score less than -2.5).

Severe Osteoporosis

It is considered to be present when the value of bone mineral content is more than 2.5 standard deviations below the mean for the young adults and there is at least one so called fragility fracture i.e. fragility assumed to be associated with osteoporosis because it occured as a result of slight trauma.

Bone Densitometry for the evaluation of periprosthetic remodelling of bone after total hip arthroplasty

Total hip arthroplasty alters the strain environment in the proximal aspect of femur and the resultant efects on bone remodelling lead to a redistribution of bone mass adjacent to the prosthesis. This sometimes results in substantial and progressive bone loss that is characterized by extensive resorption in the remodelled femur with

the greatest mean decrease in bone mineral content occuring adjacent to the proximal one-third of the femur (36,37).

Osteolysis associated with wear debris has been implicated as the dominant etiology of periprosthetic bone loss. Stress shielding also has been suggested as a cause of periprosthetic bone loss (38,39).

This evaluation and quantification of periprosthetic bone remodelling is important clinically as mechanical loosening of the implant is the most frequently reported complication of total hip arthroplasty (40).

Resorption of bone from proximal aspect of femur is an important factor contributing to the failure of total hip implants inserted with or without cement. Prosthetic loosening or fracture of femur or the prosthesis are associated with bone loss (41,42).

Consequently an accurate assessment of progressive quantifiable changes in periprosthetic bone mineral content may help the treating surgeon to determine when to intervene in order to preserve bone stock for revision arthroplasty. This information is also useful to manufactures in their efforts to redesign and improve implants and give physicians a means of determining when an unfavourable situation may develop in a prosthetic system.

Dual energy x-ray absorptiometry has been used to assess the bone mineral content of the proximal aspect of femur. Use of special software enables to determine the magnitude of loss of periprosthetic bone. Dual energy x-ray absorptiometry requres only a small volume of bone and this is appropriate for the evaluation of an osteoportic femoral shaft adjacent to a prosthesis that has been inserted with or without cement. Dual energy x-ray absoptiometry provides both the accuracy and the precision that is necessary to quantify changes in bone that occur after total hip arthroplasty (43,44).

It is well established that initial bone stock in femur has an important influence, on the extent of bone remodelling. Accordingly some advocate the use of DEXA for routine preoperative analysis of bone mineral content in order to predict the change in bone mass after total hip arthroplasty especially for patients who have poor bone stock and those who are at risk osteoporosis (45).

Therefore, DEXA provides a precise and accurate means for the evaluation of periprosthetic bone remodelling after total hip arthroplasty.

Conclusion

Bone densitometry provides critical information about osseous integrity, the risk of fracture and periprosthetic bone remodelling. Consequently an understanding of this technology is important in current orthopaedic practice.

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