Measurement of BMD in Dual-Energy X-ray Absorptiometry - A Review

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Abstract – **Application of DEXA scan in healthcare applications have recently become one of the most active research platforms. Since the DEXA exhibit novel and superior properties compared to conventional scan and create a new challenging boom in medical era. Having a deeper look into the specific features of DEXA, this paper provides a literature survey on DEXA. DEXA is the most common method used for the Bone mineral density (BMD) estimation to assess fracture risk. Only a very few papers explain the importance of DEXA and this paper explains the need of DEXA and its role in BMD. The objective of this paper is to present a survey on DEXA that appeared in the literature over the past decade under all severe conditions that were not discussed in the previous survey. The paper focuses on the Principles, fundamentals and modalities, techniques and salient contributions of DEXA.**

Keywords: Medical field, Healthcare, Dexa Images, Bone Mineral Density (BMD), Osteoporosis, T-Score, Z-Score.

I. Introduction

Early challenge of the measurement of bone mineral density used conventional x-rays. Next invention in the medical field is the discovery of single-photon absorptiometry (SPA). A radioactive source of either iodine (I-125) or americium (Am-241), with energies of 27keV and 60 keV is used in this method. The principle behind this technique is that the subject positioned his or her arm in a water bath to afford a uniform path length through which the gamma rays would pass.

Bone density is calculated by the amount of bone tissue in the region scanned by means of subtraction of the photons attenuated by the soft tissue from the photons attenuated by bone and soft tissue. This technique established a good place in medical field in terms of bone quantification, but it was limited to a peripheral site. But when bone density is to be measured at axial sites (i.e., the spine or hip), in which the soft tissue is of variable thickness, gamma rays of two different energies are required to distinguish soft tissue from bone.

Figure 1: DEXA image of spine and Femur

Dual energy problem is engaged in Dual-photon absorptiometry (DPA), use gamma rays [1]. Algebraic equations derivation is used for the estimation of bone and soft tissue. A Dual Energy X-ray absorptiometry, commonly known as densitometry or dual X-ray absorptiometry (DXA) can produce whole body image and discriminate dissimilar body structures. Likewise DPA, the basic rule of DXA is the depth of the transmission of x-rays, formed from a stable x-ray source, at high and low energies. History of various techniques for BMD measurement is listed in Table 1.A lot of papers in DEXA explained the basic principles and operation of DEXA. No review paper available to discuss the work related to the DEXA. This scenario motivated us to present a review paper in DEXA.

In this paper, our focus is on DEXA scan that are being used extensively in BMD applications. Their success rate is also very high compared to other scans used for BMD. The measurements of DEXA such as Body fat, BMD, T-Score, Z-Score, Osteoporosis, Obese etc., make them turn into popular in medical field. DEXA with its functionality can be used for diagnostic and therapeutic purposes. With the improved accessibility of DEXA, there has been a remarkable increase in its use in pediatric research and clinical practice [1]. The proximal femur, lumbar spine and the whole body are the major areas covered by the DEXA scan. The proximal femur includes the femoral neck, trochanter, Wards area and total hip. The DEXA image of the spine and femur are shown in Fig. 1.

TABLE 1
History of BMD Measurement

Technique	Principle
X-Rays	Measurement of BMD is based on the aluminum or ivory phantom.
SPA	Measurement of BMD is based on the gamma rays. Bone density is calculated by means of subtraction of the photons attenuated by the soft tissue from the photons attenuated by bone and soft tissue.
DPA	Based on the Concurrent transmission of gamma rays with photon energies of 44 keV and 100 keV from gadolinium-153.
SXA	Based on the photon source as a X-Ray system with solid state detectors
DEXA	Based on the measurement of the transmission of x-rays, produced from a stable x-ray source, at high and low energies.

Osteoporosis is a silent severe killing disease with different risk conditions. More than 2 million osteoporosis condition subjects are noticed in U.S every year [2]. This disease occurs commonly in women; in particular those who are older than 50 years, men also commonly develop osteoporosis.

The primary obstacle of osteoporosis is fractures happening after minimum trauma. Hip, vertebral, and radius fractures increase the threat of future fractures. Common features of aging are the diminishing in bone mineral. Osteoporosis is identified through DEXA as indicated by World Health Organization (WHO) in 1994. This method defines the Quality of the bone which defines the disease [2]. The features of DEXA scan is shown in Fig. 2.

This paper is organized as follows: Section 2 described the Principles of DEXA scan. Section 3 explains Fundamentals and modalities of dual energy X-ray absorptiometry. Analysis and positioning considerations in DEXA are described in section 4. BMD measurements and interpretations in DEXA are detailed in section 5. Section 6 concludes the work with detailed inference from the related reviews.

II. Principles of DEXA Scan

In the last decade, major advantages of DEXA have been found, experimented and analyzed by the researchers particularly in medical Era. The x-rays employed in diagnostic imaging and densitometry must have enough energy to pass through the body and after that it should be detected by the sensors. During the passage through the tissue, the X-ray beam energy is attenuated or reduced.
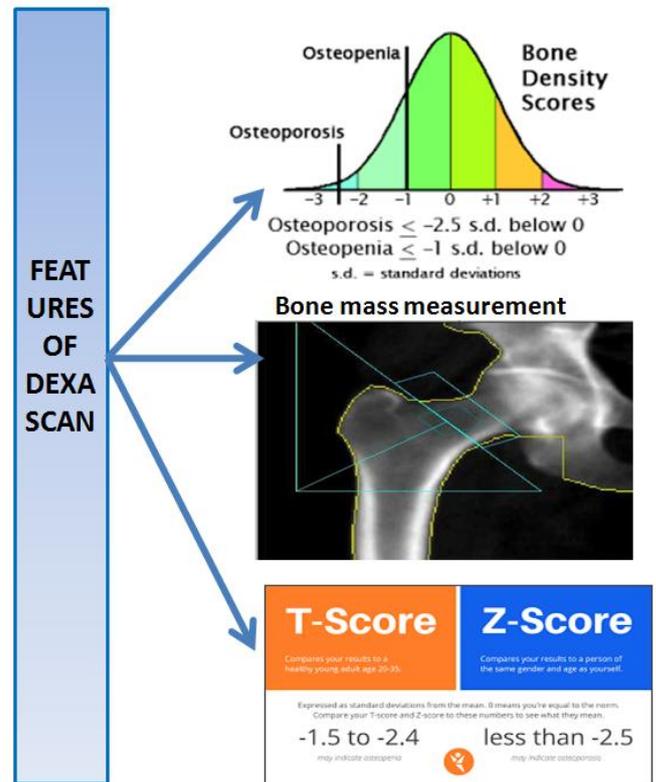
Figure 2: Various features of DEXA scan

The level of shrinking fluctuates with the energy of the photons and the density and thickness of the material through which they pass. Attenuation will follow an exponential pattern observed in other biological circumstances. For photons with the same energy radiation the format of attenuation can be illustrated using the following formula:

$$I = I_0 \, e^{-\mu M} \qquad (1)$$

Where I is the measured intensity of the x-ray; I_0 is the initial intensity of the x-ray beam; μ, mass attenuation coefficient $(cm^2 g^{-1})$ and M is the area density (g/cm^2). The various tissue densities are separated based on the higher and lower attenuation levels [1]. These are shown in Figure 3. In [2] the authors discussed that the main contributions of DEXA examinations revealed that the main output of the assessment is a factor. In [3], the author discusses about the parameters and their values in the BMD measurement.

The scanner estimates the BMD in grams per square centimetre. Based on the reference database consultation, values and curves are obtained.
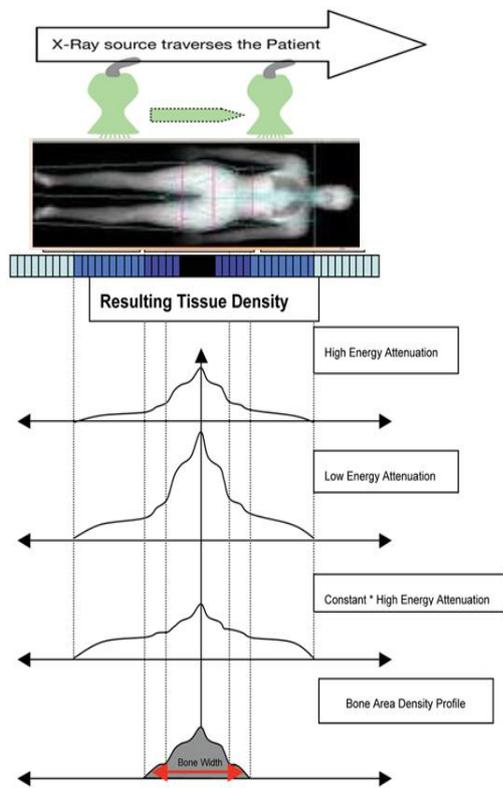
Figure 3: Tissue Density based on the attenuation

In [4] the authors explained the need for the use of DEXA instead of any other techniques. TBW takes the processing time of 3–8 h to complete, while DXA takes less than 5 min. The relation of electrical resistance and reactance to intracellular and extracellular water is done by bio impedance analysis.
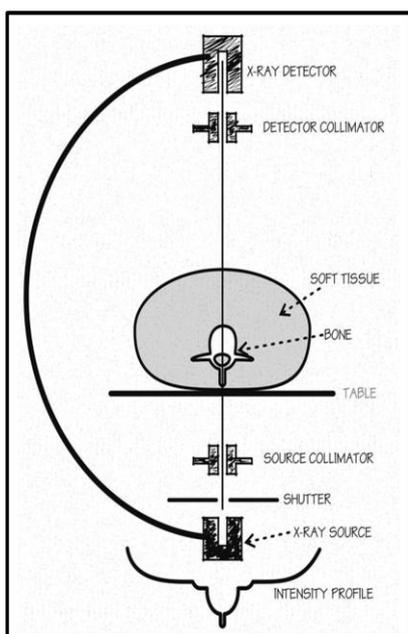

Figure 4: Schematic diagram showing the components of a DX system (courtesy of J. Shepherd, UCSF)

These measurement methods are hard to use for regional measures. Estimation of regional bone, fat and soft tissue lean distributions can be done by only imaging methods, such as DXA, Computed Tomography (CT) and Magnetic Resonance Imaging (MRI). DXA is low dose in comparison to whole body CT scanning and inexpensive compared to MRI.

III. Fundamentals and modalities of Dual Energy X-ray Absorptiometry

As discussed earlier, DXA is based on the inconsistent absorption of X-ray by the diverse body components. The photons can be extracted by means of two mechanisms depending on the equipment used. The schematic diagram showing the components is shown in Figure 4. Both hardware and software is included in the DXA systems. Different types of hardware are filters, collimators and detectors and the software involves algorithms for analysis. The X-ray source can release a pencil beam (pinhole collimator), which is registered by a single detector, or a fan beam (slit collimator), which is recorded by a multiple detector. The latter system reduces the acquisition time and progresses in image quality. The analysis algorithm differentiates bone from soft tissue in a variable way. The main modalities of DXA in clinical practice are axial bone densitometry with stationary scan table, the modality of choice to measure the BMD, and whole body densitometry, used to assess body composition [5].

3.1. Areas of study

The DXA examination in adults normally includes the lumbar spine and proximal femur; the forearm can also be included when hip or spine cannot be measured.

In the younger, that is age less than 20 years, the measurement is only involved in the lumbar spine. The postero-anterior (PA) scan of the lumbar spine includes the vertebral bodies of L1-L4, from which a mean BMD of these four vertebrae is obtained.

At least two assessable vertebrae are required in the lumbar spine. The learning of the femur can vaguely be performed on the right or left hip, although it is useful to become used to studying always the same side. The analysis of the non-dominant forearm is completed when hip or spine cannot be calculated (in order to have a second measurable region), to obese patients (to bypass technical difficulties), and to patients suffering from hyperparathyroidism (since forearm bones alter before the axial skeleton) [5]. General performance of DEXA in medical field is described in Table 2.

TABLE 2
General Performance of Dexa in Medical Field

SL No	Author	Year	Remarks
1	Nicola J Crabtreeet al. [1]	2004	Deals with the historical background of Densitometry, advantages of DEXA. The limitations such as two dimensional analysis of BMD and no bone depth are dealt.
2	Robert H.Choplin et al. [2]	2014	Deals with the procedure, positioning and BMD measurement
3	Rosa Lorente et al. [3]	2011	Deals with the image analysis, patient preparation methods and modalities.
4	Sheng, H.P., Huggins et al. [15]	1979	Deals with the principle of DEXA, BMD measurement procedure and osteoporosis.
5	R.M. Lorente Ramos et al. [12]	2012	Deals with the history of BMD, BMD measurement in DEXA and limitations of DEXA.

IV. Analysis and Positioning Considerations

We must be aware of positioning and anatomical variation in population, which can lead to erroneous report [8].The Central DEXA examination, measures bone density in the hip and spine, the patient lies on a padded table. An x-ray generator is located below the patient and an imaging device, or detector, is positioned above. To assess the spine, the patient's legs are supported on a padded box to flatten the pelvis and lower (lumbar) spine. To assess the hip, the patient's foot is placed in a brace that rotates the hip inward. In both cases, the detector is slowly passed over the area; generating images on a computer monitor [6].

V. BMD Measurements and Interpretations in DEXA

BMD measurements have an important role in the evaluation of patients at risk of osteoporosis and in the appropriate use of antifracture treatment. Fracture risk in hip in post menopausal women and elderly men are associated with the every standard deviation decrease in BMD with a three-fold increase in the age.

Genetics is the far most important factor in both women and men, where family studies and studies of monozygotic and dizygotic twins have shown that genetic factors can explain up to 80% of the variability in bone mass. Risk factors for osteoporosis are separated into those that can be modified and those that cannot be modified. Where age, heredity, previous fragility fracture, parental history of fragility fracture, female gender, and early menopause are the most important osteoporosis-related risk factors that cannot be modified. The most vital risk factors that can be modified and is related to lifestyle are smoking, inactive lifestyle, low body mass index, diet lacking in calcium, high alcohol consumption, and low

levels of vitamin-D due to lack of sunlight exposure or malnutrition . Certain medical conditions and medications like long use of corticosteroids, rheumatoid arthritis, over-active thyroid or parathyroid glands, coeliac disease and other chronic gut conditions, and chronic liver or kidney disease can cause secondary osteoporosis [7]. For the estimation of the score, a BMD test measures BMD and compares the result with a standard.

Correct interpretation of a BMD measurement will be influenced by the reason of measurement such as to diagnosis osteoporosis, to evaluate fracture risk.

In order to make meaningful interpretation, the BMD result must be expressed unambiguously, and compared to relevant reference range. We need to understand the relationship between BMD and fracture risk, and take account of additional factors that affect the risk of fracture independently of BMD itself [9]. Moreover special training to personnel to handle the DEXA equipment is also needed [10].

VI. Conclusion

In recent scenario, advanced scanning system plays a major role in medical imaging, as accuracy is needed in diagnosis and, targeted drug delivery. Table 2 provides the general performance of the DEXA in the medical field. .The applications of DEXA scan are not restricted to any issues in biomedical field. It may extend in various research fields like health and safety and societal impacts. It is substantiates that, in future the almost in all modalities, BMD plays a vital role. In a nutshell, various DEXA scan images were successfully developed and still more can be developed and they have a great potential in all therapy treatments in healthcare applications. Although accessibility of DXA may vary from

country to country, this technique is now widely available in both general hospitals and academic medical centres. Although any radiation revelation results in a degree of danger to the patient, DXA has one of the lowest effective doses of all the ionizing radiation imaging techniques, being equivalent to approximately less than 1 D naturally occurring radiation in most cases. Even though DEXA has its own advantages, it also has certain limitations. Only two dimensional measurements of bone mineral content is provided for a three dimensional bone. Also it doesn't provide the information about the bone depth. Another important issue is the failure of bone detection algorithms in pediatric DEXA Images. Thus there is a lot of scope for the researchers to carry out further research in terms of this BMD measurement of the children.

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