Bone Mineral Densitometry (BMD) Precision and Scattered Radiation Level of Dual Energy X-ray Absorptiometry (DXA) Installed in Mymensingh Nuclear Medicine Unit, Bangladesh

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Abstract

Dual Energy X-ray Absorptiometry (DXA) has long been and remains the most widely used technique for Bone Mineral Densitometry (BMD) measurement. Several manufacturers developed their performance of DXA with various types of measurement software but still not a unique data processing system which can ensure the unique measurement for the patients. The aim of this article is to show the precision level of BMD in DXA machine GE (Model: DPX Lunar) installed at INMAS, Mymensingh and to measure background radiation consistency during acquisition. A rectangular shape QA phantom of variable density for precision measurement and survey meter (Austral Rad Mini 8 in 1) for radiation monitoring were used. Coefficient of Variation for BMD values was 0.37% and always ranges from 0.32% to 0.38%. Radiation survey meter reading always showed the values ranges from 0-3 µSv/hr. It can be concluded that these good QC are not the conformity of exact measurement because there some reference values involved in T-score or Z-score measurement. These reference values were taken from healthy adult Caucasian women which are different from Bangladeshi population.

Keywords

DXA, BMD, QC, Bar Phantom, T-score, Precision

1. Introduction

1.1. Background of BMD

First Dual Energy X-ray Absorptiometry (DXA) was introduced in America in 1987 [1]. Until now three American manufacturers provide central DXA system all over the world, namely GE, Hologic and Cooper Norland. Each manufacturer offers variety of models [2]. Our DXA system is from GE (Model: DPX Lunar) was installed in 2009. It generates soft X-ray (~35 keV) and hard X-ray (~70keV) simultaneously to measure bone mineral densitometry (BMD) [3].

1.2. BMD Measurement Technique

There are several techniques used for BMD measurement. All of them are (i) Dual energy X-ray absorptiometry (DXA) (ii) Single energy x-ray absorptiometry (SEXA) (iii) Single photon absorptiometry (SPA) (iv) Radiographic absorptiometry (RA) of the finger (v) Ultrasound of the hell and (vi) Dual x-ray and laser (DXL). Among the above six techniques, DXA is the most commonly used procedure. SEXA, SPA, RA are less commonly used [4]. When DXA is done at peripheral region, it often termed as pDXA. It is regarded as the reference method for measuring bone mineral densitometry with acceptable accuracy errors and good precision and reproducibility. In addition, it is popular due to its ease of use, low radiation exposure and its ability to measure BMD at both hip and spine. It examines overall skeletal changes that often happen with age by measuring bone mineral content and bone mineral density. Moreover, total body fat and lean muscle mass value from DXA give the concrete idea into the effect of age, sex and race on the skeleton. The World Health Organization (WHO) has recognized the DXA scan as the most suitable densitometric technique for assessing BMD in postmenopausal women [5]. WHO’s definition for osteopenia and osteoporosis are expressed in terms of dimensionless statistical parameter T-score or Z-score. T-score is defined as the difference
between the patient’s BMD value and the mean BMD value of a young reference population divided by the standard deviation in BMD values for the same defined reference population. Mathematically, it is stated as the following equation (1).

\[ T-score = \frac{x - \bar{x}}{s} \]

Here,

\[ \bar{x} = \frac{\sum x}{N} = \frac{x_1 + x_2 + \cdots + x_N}{N} \quad \text{and} \quad s = \sqrt{\frac{\sum (x - \bar{x})^2}{N - 1}} \]

Where, \( x, \bar{x} \) and \( s \) correspond to patient BMD value, mean BMD value of reference population and standard deviation of reference population respectively. \( N \) is number of sample size.

In order to get optimal benefit from DXA system good operation is not sufficient. It needs routine QA check. Though DXA has long been, and remains, the most widely used technique for BMD measurement, then DXA acceptance tests are not well established on which measurement accuracy and precision depend on. The offset of measuring values depend on low radiation dose, outpatient department, acquisition by nurses rather radiographer, lack of medical physicist input in its error, accuracy, precession etc [6]. The term accuracy is how close a measured value is to the actual (true) value and the precision is how close the measured values are to each other. The measurement of precision that is coefficient of variation (CV%) is expressed as equation (2).

\[ \%CV = \frac{s}{\bar{x}} \times 100 \]

The accuracy and precision of BMD measurement must be maintained at the highest level so that actual biological changes can be detected with even slight changes in BMD [7]. Available tests those ensure the forgoing criteria are Radiation Output Consistency, Half Value Layer, Field Size, Fan Angle, Spatial Resolution, Electrical Safety [8]. All tests are not possible to conduct in DXA system in Bangladesh due to lack of technical support. Cross calibration is another important QC for DXA system to compare the values obtained from another different DXA system. From this result one can assume that how precise the measured BMD values are. But in this method two DXA systems are required.

### 2. Materials and Methods

#### 2.1. Precision

For precision measurement the system uses GE Lunar en CORE software. A rectangular shape QA phantom of variable density, 6cm thickness, 15cm width and 20cm long is used in this study. This supplied QA Phantom is fabricated with three bone equivalent mass of different density known as High, Medium and Low which correspond to fat, medium and lean body mass respectively. Only two important parameters those are taken into account numerically are BMD (measured in g/cm²) and composition content (measured in %) of three bone equivalent masses of the phantom. Among composition content only the fat percentage are calculated. The scanner uses 76 kVp X-ray tube with a tungsten target and a K-edge cerium filter [9]. The filter’s k-edge absorption at 40 keV splits the X-ray beam into two discrete energy bands. The energy portion known as soft x-ray is centered at ~38 keV and high energy portion known as hard X-ray is centered at ~ 68 keV [10]. Then the beam is collimated into a narrow fan beam with 4.5° opening angle, passes through the object, and is absorbed by an energy sensitive cadmium zinc telluride (CZT) detectors. This detector consists of a linear array of 16 discrete CTZ detector of 7 mm × 3mm area, placed with 3.2 mm pith [9]. During precision measurement the phantom is placed on the table along with the laser an X-ray beam passes through the phantom in upward direction. Depending on the attenuation of two energy level, the system provide quantitative data on the bone mineral content (BMC) and fat content from three fat, normal and lean body bone equivalent mass. From BMC value, BMD is calculated by multiplying projection area of the bones. Here it should be kept in mind that DXA BMD is a projectional value and not a true volumetric measurement; so it is independent of bone size [9]. Scanning time requires 12-15 minutes. Within a 12×15 cm field of view, the transmitted energy is detected by a cadmium-telluride detector mounted on the L-arm of the system [10]. This daily QA program evaluates not only BMD and composition content calibration but also includes database validation, scanner self test, peaking, mechanical test, X-ray detector test and phantom status. These tests are done automatically one after another. After completing every test successfully ‘pass’ sign come automatically. At the conclusion of the scan, the step phantom scanning image is automatically analyzed and the data are stored in a separate database of the system. Then BMD values of three masses are plotted against time in one graph and fat content of three different masses are plotted in another one against time. For precision measurement, BMD coefficient of variation is then calculated.

#### 2.2. Radiation Survey

As there some legal bindings, so the system must meet the IAEA and national guidelines for safety, licence, radiation exposure. Though DXA scanner uses low radiation dose, it is important to survey scattered radiation at a distance of one meter from the closest edge of the densitometer while performing phantom scan in order to save technologist, medical physicist and doctor from excess radiation [11]. This is done regularly by survey meter. Survey meter reading is expressed as dose equivalent unit μSv/hr.
3. Results

3.1. BMD & BMC

BMD in g/cm²

Figure 1. QC plot for BMD. The machine is functioning within the pre-specified range of BMD.

%Fat

Figure 2. QC plot for composition content. Proper machine functioning is observed.

Figure 3. Two dimensional image of step phantom after scan acquisition. The QA plot window that appeared in computer screen are shown as figure 1 for BMD calibration and figure 2 for composition content calibration for one year. In both figures, the values are scattered in horizontal pattern around the 0 value and a little bit rising or falling pattern are observed. This indicates apparently high precision. The visual examination of two QC figures can be compared with either process control CUSUM (cumulative sum) chart or Shewhart chart. CUSUM and Shewhart charts are both useful in monitoring long-term quality control [12]. In this case, CUSUM chart is more appropriate. Because Shewhart chart is sensitive to sudden and large changes in measurement; it is less effective in detecting small change [13]. In both QC-plots, there are large gap in middle. During this period the machine was not functioning due to some technical problem. Two dimensional image of block phantom appears as in figure 3 during acquisition. In table 1, two parameters are displayed. According to the standard level of acceptance, the Coefficient of Variation (CV) of BMD should be at or below 0.60 percent [14]. Our daily measured CV for BMD always ranges from 0.32% to 0.38%. These values satisfy the manufacturer’s specification. On the other hand, CV for composition content is not quantified here. But in visual observation, the values are very close to each other i.e., good precision.

Table 1. Overall QC values and their status

| QA Phantom | Value     | Status |
|------------|-----------|--------|
| BMD        | 1.003 g/cm² | Pass   |
| BMC        | 23.52 g    | Pass   |
| Area       | 23.44 cm²  | Pass   |
| Precision/BMD CV | 0.37%     |        |

| QC Tests                | Status |
|-------------------------|--------|
| X-ray and Detector status | Pass   |
| Mechanical Tests        | Pass   |
| Calibration Status      | Pass   |

3.2. Survey Meter Value

Survey meter reading always ranges from 0-3 µSv/hr during the acquisition which satisfy the IAEA guidelines.

4. Discussion

Osteoporosis is a worldwide severe health problem. BMD has evolved into the “gold standard” for its diagnosis and treatment evaluation [15]. So the T-score, a leading diagnostic marker for osteoporosis, must have to put into proper context. From ongoing research in different countries, it is established that T-score is suitable for post menopausal women and Z-score is suitable for young adult [16]. But in Bangladesh all patients are evaluated with respect to T-score. Three main sources of inaccuracy and imperfection of DXA scans are equipment, technologist, and patient. Inhomogeneity of soft tissue composition within the patient and its variation with time affects BMD accuracy [2]. Patient positioning is also important. Patient should be oriented as similar to reference population. There are some artifacts happened when exist such as surgical clips, navel ring, metal from zipper, coin, clip, and other metallic object to the patient body which may cause change in evaluation of
patient BMD to a great extent [5]. ROI selection is vital and it depends on data interpretation skill. Moreover, in DXA scan, absorption of soft x-ray in soft tissue is considered to be constant in all patients [9]. While DXA scan, signal data loss through the air in between the patient and the detector are not taken into account. In addition, though daily QC ensures the manufacturer’s specifications but there may come some errors in T-score or Z-score measurement. Because healthy adult Caucasian women’s reference values may not be agreed with Bangladeshi women’s reference value (BMD reference values of Bangladeshi women is not yet established). Considering this fact, a preliminary study was performed in NINMAS located at BSMMU campus Dhaka, Bangladesh. They found a significant difference between young healthy reference value of Bangladeshi population and that of manufacturer for BMD [17].

5. Conclusions

Osteoporosis has become a chronic disease in present time. This disease needs to be kept under control. BMD, T-score and Z-score values are changed from device to device even using the same phantom. These changes can affect the type of treatment (as osteopenia, osteoporosis or normal) [18]. From this study, it can be concluded that good QC result is not only the conformity of our measured BMD accuracy, because there are some reference values involved in T-score or Z-score measurement. These reference values were taken from healthy adult Caucasian women. It should be taken from Bangladeshi population. So it is needed to modify software (using new reference value) to get more concrete result which is applicable for Bangladeshi population.

REFERENCES

[1] A. Larkin. Accuracy of DEXA scanning & other methods for determining BMD. Online available from http://www.dimon d3.org/Dublin 2006/2 DEXA QA TrainingforPhysicists/7 Accuracy of DEXA other methods.pdf.

[2] H. S. Bennett, A. Dienstfrey, L. T. Hudson, T. Oreskovic, T. Fuerst, J. Shepherd. Standards and Measurements for Assessing Bone Health – Workshop Report Co-Sponsored by the International Society for Clinical Densitometry (ISCD) and National Institute of Standards and Technology (NIST), Journal of Clinical Densitometry, Vol. 9, No.4, 399 – 405, 2006.

[3] W. Evans. Principle of operation of DEXA systems, University Hospital of Wales, Cardiff. Online available from http://www. Dimond3.org/.

[4] Peripheral Bone Mineral Density Measurement. Online available fromhttp://www.anthem.com/medicalpolicies/poli cies/mp_pw_a050533.htm.

[5] A. EL MAGHRAOUI, C. ROUX. DXA scanning in clinical practice, Q J Med., Vol.101, 605–617, March 2008.

[6] N. Sheahan. Quality control Protocol for DEXA systems, Medical Physics and Bioengineering. St. Jame’s Hospital, Dublin. Online available fromhttp://www.dimon d3.org/Dublin%202006/1%20RP%20Training%20for%20DEXA%20operators/3%20QA%20Protocol%20for%20DEXA%20System s.pdf.

[7] K. Ho-Sung, Y. Seoung-Oh. Quality Control of DXA System and Precision Test of Radio-technologists, J Bone Metab, Vol. 21, 2-7, 2014.

[8] L. Gray. Technical Issues & System Performance: Results & Findings of EU DEXA Study II. Online available from http://www.dimon d3.org/Dublin%202006/1%20RP%20Training%20for%20DEXA%20operators/5%20QA%20Technical%20Results.pdf.

[9] J. Wear, M. Buchholz, R. Payne, D. Gorsuch, J. Bisek, D. Ergun, J. Grosholz and R. Falk. CZT detector for dual energy x-ray absorptiometry (DEXA), Edward J, Vol. 41, No. 42, 175-188, December 2000.

[10] E. M. Lochmüller, V. Jung, A. Weusten U. Wehr, E. Wolfand F. Eckstein. Precision of high-resolution Dual Energy X-ray Absorptiometry Measurements of Bone Mineral Status and Body Composition in Small Animal Models. European Cells and Materials, Vol.1, 43-51, 2001.

[11] A. A. Khan, J. Brown, K. Faulkner, D. Kendler, B. Lentle, W. Leslie, P. D. Miller, Nicholson, W. P. Olszynsk and N. B. Watts. Standards and Guidelines for Performing Central Dual X-Ray Densitometry from the Canadian Panel of International Society for Clinical Densitometry, Journal of Clinical Densitometry, Vol. 5, No. 4, 435– 445, Winter 2002.

[12] D. Pearson, S. A. Cawte. Long-Term Quality Control of DXA: A Comparison of Shewhart Rules and Cusum Charts, Osteoporosis Int, Vol. 7, 338-343, 1997.

[13] M. A. Boyanov. Quality Control of DXA System and Precision Test of Radio-technologists, Central Medical Library, Sofia, 2013.

[14] National Health and Nutrition Examination Survey (NHANES). Body Composition procedure manual, January 2006.

[15] A. E. Maghraoui, L. Achemlal, and A. Bezza. Monitoring of Dual-Energy X-ray Absorptiometry Measurement in Clinical Practice, Journal of Clinical Densitometry, Vol. 9, No. 3, 281–286, July 2006.

[16] National Health and Nutrition Examination Survey (NHANES). Dual Energy X-Ray absorptiometry (DXA) Procedures Manual, 6-7, January 2007.

[17] F. A. Hossain, M. Haque, L. Nisa. Standardization of Bone Mineral Density (BMD) for Bangladeshi Population- A preliminary Study, B J of Nuclear Medicine, Vol. 13, No. 1, 16-19, January 2010.

[18] D. Tuncman, H. Kovan, B. Kovan, B. Demir, C. Turkmen. A systematic quality assurance study in bone densitometry devices, EPJ Web of Conferences, Osmaniye, Turkey, No. 03004, 1-2, 2015.