

The Application of a Water Filter to Reduce Radiation during Bone Mineral Densitometry (BMD)

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Abstract

In order to provide a set of basic data that can help to minimize the radiation during bone mineral densitometry and to acquire an optimal image for diagnosis, a water filter was used with a glass dosimeter to acquire an image, and the T-score and Z-score between the image and the radiation amount were measured. Radiation amount was $18 \pm 0.36 \mu\text{Gy}$ for the lens, $17 \pm 0.42 \mu\text{Gy}$ for the thyroid, $18 \pm 0.33 \mu\text{Gy}$ for the breasts, $19 \pm 0.41 \mu\text{Gy}$ for the heart and $18 \pm 0.35 \mu\text{Gy}$ for the reproductive organs. When the water filter was applied by 1cm, 2cm, 3cm, 4cm and 5cm, the radiation decreased by 11.1%. The acquisition of the same T-score and Z score before and after the application of a water filter was to 1cm and for 2cm or more; the same values for T-score and Z-score could not be acquired. The results are expected to provide a basic set of data in forecasting the application of water filters during BMD and determining the test method, leading to reduced radiation.

Keywords: Bone Density, Glass Dosimeter, Radiation, Shielding, Water Filter

1. Introduction

A Bone Measurement Densitometry (BMD) is a test that measures the bone density of a specific site of the body, compare it with the bone density of a normal person and evaluate how much the mass of bone has decreased^{1,2}. There are various types of BMD methods; measuring the absorption of radiation, Dual Energy X-Ray Absorptiometry (DEXA) where a low energy X-ray and a high energy X-ray are shot to use the resulting data to measure bone density, Quantitative Ultrasound (QUS), quantitative computer tomography and quantitative MRI testing. Among these, the most commonly used method is the dual energy X-ray absorptiometry or DEXA³⁻⁵.

The diagnosis of osteoporosis using DEXA calculates the bone density value in the lumbar vertebra and the femur by measuring how much of the substance passes through the body. The values were compared against the average for each gender and age to conclude a Z-score, and through a comparison against the bone density of healthy subjects in their 20s and 30s the difference is quantified into a T-score.

The diagnosis of osteoporosis followed the definition by World Health Organization (WHO). That is, depending on the T score, the subject can be ruled as normal (-1.0 or higher), osteopenia ($-2.4 \sim -1.1$), or osteoporosis (-2.5 or lower). The higher the negative value, the more severe the loss of bone mass^{6,7}. The cost and frequency of bone densitometry is on a drastic increase along with a general increase in medical check-ups^{1,8}. The parts where the lumbar vertebra and femur are located are the sites where the breasts, heart and reproductive organs are located and where it is said to show changes due to radiation from frequent densitometries, according to the guidelines by the International Committee Radiation Protection (ICRP). In its 60 guidelines, ICRP recommended a tissue weight coefficient of 0.05 for the remainder tissue that include the breasts, uterus, prostate and heart. But it later upgraded its recommended coefficient to 0.12 in its 103 guidelines. Such a change indicate that caution is needed not only in tests that use high energy rays but also in tests that use low energy rays for medical check-ups⁹⁻¹⁷.

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Studies on radiation related to osteoporosis include an evaluation of the effectiveness of a breast shield to reduce radiation of the breasts from scattered rays³, reduction of radiation caused by limited changes possible in posture during the densitometry⁴ and a study measuring the distribution of scattered rays within the dual ray densitometry device.

However, these studies were based on the exposure dose measurement device or the does evaluation by automatic exposure devices, while there were practically no studies on radiation using a glass dosimeter which is highly reliable in terms of energy, direction with less fading effects and a wider range of measurable rays. It also makes accumulative radiation measurement possible and is a measurement device using a substance that is equivalent to the human tissue.

Radiation exposure due to diagnostic radiation use is increasing and among them artificial radiation takes up the largest share^{10,12}. In order to minimize the effects on the human body by diagnostic X-rays, more studies on radiation exposure of remainder tissue including the breasts, uterus, prostate and heart which have a higher tissue weight, are needed.

In this study, a glass dosimeter and water filter that were built by the researcher was used in the BMD to measure the radiation amount, in order to provide a basic set of data that can contribute to acquiring an optimal image while minimizing radiation exposure.

2. Study Methodology and Subjects

2.1 Materials and Equipment

For the X-ray generator, DEXA (Dual Energy X-ray Absorptiometry) manufactured by Osteosis Company, the DEXXUM T was used. In order to measure the radiation exposure of the subject, a body phantom made of equivalent substances to that of the human body (Model PBU-31, Kyoto Kagaku, Japan) and Dose Ace, a glass dosimeter (Model GD-352M and FGD-1000, Asahi Techno Glass Cooperation, Shizuoka, Japan) were used.

2.2 Measurement of the Radiation using the Glass Dosimeter



Figure 1. Radiation generator and phantom.

The calibration of the glass dosimeter was done using the glass element that was exposed with 6 mGy using ¹³⁷Cs standard ray source at Japan's Standard Radiation Center. Given the characteristics of the element, before the exposure, annealing was carried out at 400 degrees Celsius for 1 hour, after which it was cooled and its background value was measured. The background value was 10-20 µGy. After a panorama scan, pre-heating was carried out at 70 degrees Celsius for one hour, then cooled. The radiation value that was exposed to the element was measured 10 times repeatedly to calculate the mean and standard deviation. From these values, the background value was subtracted to conclude the radiation value^{11,13}.

During a BMD, the measurement of scattered radiation rays was done by locating the glass radiation element in the sites of the lens in both eyes, the thyroid, the two breasts, heart and reproductive glands. In order to reduce measurement errors, breast images were taken three times.

2.3 Measurement of T-Score and Z-Score

Using a dual X-ray and a DEXA method to the spine and femur, the transpired ray amount was acquired by the director. From the bone image thus acquired, the bone density within the ROI was calculated. This was then compared against the average for each gender and age to calculate the Z-score. The bone density was also compared against that of healthy subjects in their 20s and 30s to quantify the difference between the two groups, and calculate the T-score (Figure 2).

For the BMD, a standard method of designating an ROI (Region of Interest) was used. Number 1, 2, 3 and 4 of the lumbar vertebra were measured, as well as the neck of the femur, the trochanteric area,

the intertrochanteric area and Ward's area⁵. In order to increase the confidence level for measured values, all measurements were taken on the same site three times and their mean was used for analysis^{13,14}.

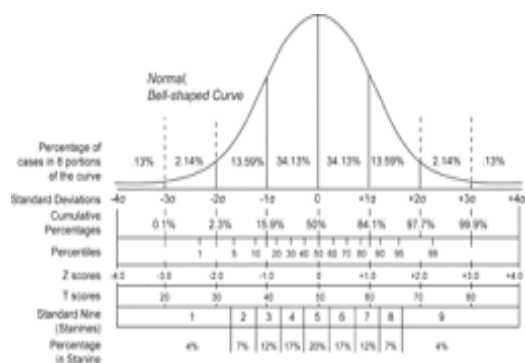


Figure 2. Statistical understanding of the T-score.

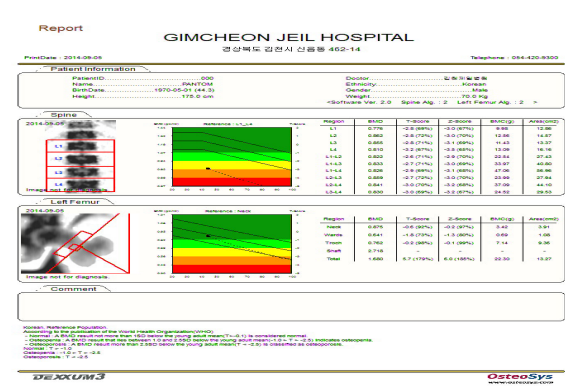


Figure 3. Schematics the measurement results.

3. Results and Review

3.1 Distribution of the Exposure dose during BMD of the Femur and the Lumbar Vertebra

BMD tests diagnoses situations where the bone mass have decreased and qualitative changes in the bone have undermined the strength of the bone, increasing the risk of fractures. This diagnosis helps make a ruling on whether osteoporosis has taken place.

There are two ways to measure bone density; to use ultrasound and to use X-rays. When ultrasound is used, the calcaneus is tested using ultrasound to judge whether there is osteoporosis. In such a case, the device is small and thus provides portability but the results may differ from those acquired through X-ray tests.

In order to diagnose osteoporosis using X-rays, tests are conducted on the forearm, the tibia and the lumbar spine. Test methods can include dual energy X-ray absorptiometry (DXA) and quantitative CT. Of these DXA is the more commonly used standard method and provides a reference point for setting insurance payouts.

While the method using X-rays has the advantage of reconstituting the images in three dimensions to make a judgment on the actual bone density, the fallback is the increased radiation exposure.

This study conducted an experiment using a water filter with a DXA method, the most commonly used methods in hospitals, in order to determine whether this can lead to reduced radiation exposure doses.

Moreover, the study seeks to present measures to reduce exposure doses during BMDs.

During the BMD in the experiment, the measurement of dose exposure was done at the standard setting for Hospital A, which is 140 and 100kVp (Dual energy), 2.5mA for 15 seconds, conducting the test on the femur and the lumbar spine simultaneously.

When a water filter was not used, the exposure dose was 18+/-0.36 μ Gy for the lens, 17+/-0.42 μ Gy for the thyroid, 18+/-0.33 μ Gy for the breasts, 19+/-0.41 μ Gy for the heart and 18+/-0.35 μ Gy for the reproductive organs. These values are in line with the results found in the study by³.

When a water filter was used, the exposure dose of the lens was measured as 16+/-0.27 μ Gy up to 1-5 cm of the water filter, indicating a 11.1% decrease in the exposure dose compared to when the water filter was not used.

As for the thyroid, the measurement was 16+/-0.29 μ Gy up to 1-2 cm of the water filter and 15+/-0.32 for 3-5 cm of the water filter, indicating a decreased exposure dose by 11.7%.

For the breasts, the measured value was 16+/-0.32 μ Gy up to 1-5cm of the water filter, showing a 11.1% reduction in exposure dose.

As for the heart, exposure dose was measured to be 17+/-0.28 μ Gy up to 1-5cm of the water filter, indicating a 10.5% decrease in the exposure dose compared to when no water filter was used.

For the reproductive glands, a measurement of 17+/-0.32 μ Gy up to 1-2 cm of the water filter and 16+/-0.24 μ Gy up to 3-5cm of the water filter were observed, which meant a 11.1% decrease in exposure dose.

The above findings show that when a water filter is applied,

in organs that require caution for radiation exposure saw a decrease of 11.1% in their exposure dose. This finding is in contrast with the results of the study by³, where a lead shield was used and the exposure dose decreased in direct proportion with the thickness of the shield, up to a maximum of 60%³.

This finding shows that water filters can be a useful tool to reduce exposure dose, but that the thickness of the shield is not proportionate to the reduction effect. Instead, 1 cm of water filter was enough to bring about a decreased exposure dose.

The result is expected to serve as an important data point in using water filters as a shield against radiation exposure during bone density tests.

3.2 Changes in the T-score in Tests for the Lumbar Spine and the Femur

The subject for the bone density test was placed to use dual energy X-rays on the inspection site so as to acquire images of the lumbar spine and the femur.

Region of Interest (ROI) was designated. For the femur, the neck, trochanteric area, the intertrochanteric area and Ward's area were measured. The measurements were then compared against the bone density of normal subjects of the same gender in their 20s and 30s. The difference in values was quantified to calculate the T-score, which is shown in Table 2.

When a water filter was not used for the femur, the T-score value was -0.6 in the neck, -0.2 in the trochanteric area and -1.8 in Ward's area.

T-score changes in accordance with changes in the thickness of the water filter were measured. For a thickness of 1-5 cm, the measurements were -0.6 in the neck, -0.2 in the trochanteric area and -1.8 in Ward's area, which are all exact same values.

The bone density test for the lumbar spine was done using a dual energy X-ray. In the acquired images using this method, ROI (Region of Interest) were set at number 1,2,3 and 4 of the vertebrae to calculate the T-scores, which are shown in Table 2.

Table 1. Distribution of exposure dose in BMD

Part	Water Filter thickness(cm)					
	0	1	2	3	4	5
Lens	18 ± 0.36	16 ± 0.23	16 ± 0.26	16 ± 0.26	16 ± 0.33	16 ± 0.31
Thyroid	17 ± 0.42	16 ± 0.33	16 ± 0.27	15 ± 0.31	15 ± 0.33	15 ± 0.31
Breast	18 ± 0.33	16 ± 0.37	16 ± 0.33	16 ± 0.23	16 ± 0.27	16 ± 0.32
Heart	19 ± 0.41	17 ± 0.36	17 ± 0.27	17 ± 0.25	17 ± 0.29	17 ± 0.26
Gonad	18 ± 0.35	17 ± 0.31	17 ± 0.33	16 ± 0.23	16 ± 0.26	16 ± 0.23

Table 2. Distribution T-score change with the thickness variation of the water filter

Part	Water Filter Thickness (cm)					
	0	1	2	3	4	5
neck	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
troc	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
inter						
ward's	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8
L1	-2.8	-2.8	-2.8	-2.8	-2.8	-2.8
L2	-2.8	-2.8	-2.9	-2.9	-2.9	-2.9
L3	-2.8	-2.8	-2.9	-2.9	-3.1	-3.3
L4	-3.2	-3.2	-3.4	-3.5	-3.8	-4.0

When a water filter was not used for the lumbar spine, the T-scores were -2.8 for number 1, -2.8 for number 2, -2.8 for number 3 and -3.2 for number 4.

When a water filter of 1 cm was used, the T-scores were scores were -2.8 for number 1, -2.8 for number 2, -2.8 for number 3 and -3.2 for number 4, which are all exact same values as when a filter was not used.

When a water filter of 2-5 cm was used, the T-scores were measured as different from when the filter was used or as seen in Table 2.

Such results indicate that in order to accurately diagnose osteoporosis while reducing exposure dose, 1cm is the most appropriate thickness. It shows that when a thicker filter is used in an attempt to further reduce exposure dose, the value for the osteoporosis diagnosis deviates too much from the true value.

3.3 Changes in the Z-score in Tests for the Lumbar Spine and the Femur

Using a bone image acquired from a dual energy X-ray absorptiometry (DXA), the bone density values of the ROI (Region of interest) were calculated. These values were then compared against the average bone density for each gender and age. Table 3 shows the results.

The Z-score in the femur when a water filter was not used was -0.2 in the neck, -0.1 in the trochanteric area, and -1.3 in Ward's area. Z-scores measured in accordance with the changes in the thickness of the water filter showed that the Z-scores were -0.2 in the neck, -0.1 in the trochanteric area, and -1.3 in Ward's area, which are the exact same values across different water thickness.

Table 3. Z-score change with the thickness variation of the water filter

Part	Water Filter Thickness(cm)					
	0	1	2	3	4	5
neck	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
troc	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
inter						
ward's	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3
L1	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0
L2	-3.0	-3.0	-3.0	-3.0	-3.1	-3.1
L3	-3.1	-3.1	-3.1	-3.1	-3.3	-3.6
L4	-3.5	-3.5	-3.7	-3.4	-4.0	-4.2

Z-scores in the lumbar spine when a water filter was not used were -3.0 in number 1, -3.0 in number 2, -3.1 in number 3 and -3.5 in number 4.

When a 1cm water filter was used, Z-scores were -3.0 in number 1, -3.0 in number 2, -3.1 in number 3 and -3.5 in number 4, which are the exact same values as when a filter was not used.

When a water filter of 2-5cm was used, Z scores were different from when no water filter was used. The results are shown in Table 3.

Such results show that in order to accurately diagnose osteoporosis while reducing exposure dose, 1cm is the most appropriate thickness. It shows that when a thicker filter is used in an attempt to further reduce exposure dose, the value for the osteoporosis diagnosis deviates too much from the true value. In other words, only when an accurate T-score and Z-score are measured can osteoporosis be accurately diagnosed and a diet and drug treatment tailored to the symptom be effective. If an inappropriate water filter is applied, it can serve as an obstacle to accurately diagnosing osteoporosis and its symptoms.

The above findings suggest that when conducting a bone density test, to minimize exposure dose of radiation and accurately diagnose osteoporosis, a water filter of 1 cm is most appropriate. Moreover, attention must be paid and efforts must be made by medical professionals in order to ensure that the effects of radiation on the human body are kept to a minimum. Regular training for medical professionals dealing with X-rays, conducted by X-ray-related associations or organizations on the topics of exposure dose and image quality, can help minimize exposure dose while securing legitimacy of such tests. These efforts will have to be made to achieve the goal of optimizing radiation defense of the patient.

4. Conclusion

This study measured the T-score and Z-score using the images acquired while a water filter and glass dosimeter were applied during an X-ray to check bone density. This was done with an aim to seek measures to minimize exposure dose and contribute to better images. Radiation amount was $18 \pm 0.36 \mu\text{Gy}$ for the lens, $17 \pm 0.42 \mu\text{Gy}$ for the thyroid, $18 \pm 0.33 \mu\text{Gy}$ for the breasts, $19 \pm 0.41 \mu\text{Gy}$ for the heart and $18 \pm 0.35 \mu\text{Gy}$ for the reproductive organs. When the water filter was applied by 1cm, 2cm, 3cm, 4cm and 5cm, the radiation decreased by 11.1%. The acquisition of the same T-score and Z score before and after the application of a water filter was to 1cm and for 2cm or more, the same values for T-score and Z-score could not be acquired.

The results are expected to provide a basic set of data in forecasting the application of water filters during BMD and determining the test method, leading to reduced radiation.

5. Acknowledgement

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