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Correlation of bone density, body mass index and radiation dose in the digital radiography system

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***Abstract*---**Background/Objectives: This study aims to provide the direction for reducing the exposure dose in patients by analyzing the PACS data of patients who received both lumbar spine bone mineral density & lumbar spine X-ray examination, understanding the correlation between BMD & BMI of the DR system, and mAs, finding the dose determinants, and then providing the basic data for the calculation of diagnostic reference level of Korean people.Methods/Statistical analysis: Focusing on the bone mineral density test data saved in PACS, this study researched the data of patients who received the lumbar spine X-ray within four months from the test date. The BMI and BMD were recorded through the bone mineral density image while the mAs and kVp were recorded through the bone spine X-ray image.Findings: Results of the multiple regression analysis, only the BMI showed the causality with mAs while the BMD and T-score did not have significant causality with dose.Improvements/Applications: The BMI formed the linear causality with medical exposure of patients. Therefore, if this is used as a tool for calculating the dose by the novice radiological technologists who have just started their radiographic work, it would be possible to reduce the unnecessary exposure of patients. Furthermore, if a prospective study is conducted by collecting the large-scale data using the results of this study as the basic data, it would be helpful for establishing the national diagnostic reference level.

***Keywords*---**bone mineral density, body mass index, digital radiography, diagnostic reference level, medical exposer.

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Introduction

The diagnostic X-ray examination has been settled down as an important tool of modern medical science for diagnosing diseases (1). In particular, owing to the introduction of digital image, the image acquisition was developed from film/screen (FS) system to computed radiography (CR) system, which is currently changing to digital radiography (DR) system in many medical institutions. The DR system is predicted to be more increasing due to the easiness of patient data management and image post-processing function (2). Because of the wide latitude of DR system, even if an image is obtained through the exposure dose higher or lower than the optimum dose, the excellent quality of image could be obtained by controlling the concentration and brightness. Thus, it could be ambiguous for users to set up the objective index or subjective standard of proper exposure dose (3, 4).

The DR system using auto exposure control (AEC) that automatically controls the test condition according to the thickness of subjects, tends to increase the exposure dose contrary to the use environment of the traditional FS system. AEC does not change tube voltage (kVp) according to the disease and body type of patients, so the irradiation time is lengthened, which could be led to the increase of tube current (mAs) and exposure dose (5, 6).

According to the statistics of the number of national diagnostic medical radiation cases & exposure dose, published by the Korea Disease Control & Prevention Agency in 2021, the number of diagnostic X-ray examination cases is about 370 million cases in 2019, which is increasing every year (7). Despite the delicate technical development of medical radiology, the frequency of treatment and the medical radiation exposure shown in the process of treating patients are increasing (8). The increase of radiation exposure could increase the crucial effect and stochastic effect on diseases like cancer or leukemia, which is a concern in modern society (9). In this sense, the research activities for minimizing the radiation exposure are actively performed in the international society. Following the recommendation of international commission on radiological protection (ICRP) 103, Korea has established the diagnostic reference level since 2006, which is continuously upgraded till today (10, 11).

Therefore, this study aims to provide the direction for reducing the exposure dose in patients by analyzing the picture archiving and communication system (PACS) data of patients who received both lumbar spine bone mineral density & lumbar spine X-ray examination, understanding the correlation between bone mineral density (BMD) & bone mass index (BMI) of the DR system, and mAs, finding the dose determinants, and then providing the basic data for the calculation of diagnostic reference level of Korean people.

Materials and Methods

Source population

From June 2014 to June 2019, the research was conducted targeting total 168 patients who received the lumbar spine bone mineral density and lumbar spine

X-ray examination in K university hospital located in Seoul. Regarding sex, there were 29 men and 139 women. The mean age was 64.36 ± 13.29. In case of age group, 25 patients under 49 years old (14.9%), 34 patients 50 ~ 59 years old (20.2%), 39 patients 60 ~ 69 years old (23.2%), and 70 people over 70 years old (41.7%). The mean height was 1.56 ± 0.08 m; the mean weight was 58.96 ± 11.34 kg; and the mean BMI was 24.07±4.07. The intervals of each test date were mean 31.35 ± 39.73 days (Table 1).

Table 1. Demographic information

Variable		n (%) or Mean ± SD
Gender	male	29 (17.3)
	female	139 (82.7)
Age [year]		64.36 ± 13.29
Ages	Under 49 years	25 (14.9)
	50 – 59 years	34 (20.2)
	60 – 69 years	39 (23.2)
	Over 70 years	70 (41.7)
Height [m]		1.56 ± 0.08
Weight [kg]		58.96 ± 11.34
BMI		24.07 ± 4.07
Exam interval date		31.35 ± 39.73
SD; standard deviation		

BMD System

The bone mineral densitometry used for this study was dual energy X-ray absorptiometry (DEXA, Hologic Inc., Bedford, MA, USA) system, and the DR system was Carestream X-ray System (Carestream Health, Inc., NY, USA) and Canon X-ray System (CXDI, Canon, Inc., Tokyo, Japan).

Study method

Focusing on the bone mineral density test data saved in PACS, this study researched the data of patients who received the lumbar spine X-ray within four months from the test date. The BMI and BMD were recorded through the bone mineral density image while the mAs and kVp were recorded through the bone spine X-ray image.

Statistical analysis

Measured data were compared and analyzed using SPSS (Ver. 25.0, SPSS Inc., Chicago, Ill, USA) statistics package program to confirm each group's statistical significance. Statistical significance was considered at $p < 0.05$.

Results

The mean tube voltage used in the DR system was 82.18 kVp, and the mean tube current was 36.89 mAs. In case of BMD test, the mean value of BMD was 2.35; the mean T-score was –1.20; and the mean Z-score was 0.33 (Table 2).

Table 2. Values of DR and DEXA

Variable		Mean ± SD
DR	kVp	82.18 ± 2.32
	mAs	36.89 ± 14.10
DEXA	BMD	2.35 ± 7.24
	T-score	-1.20 ± 1.38
	Z-score	0.33 ± 0.97

SD; standard deviation

In the results of conducting the Mann-Whitney U test according to sex, there were no statistically significant differences in mAs and BMI. The value of BMD was higher in women than men as much as mean 1.68. The T-score was higher in men than women as much as mean 0.56 (Table 3).

Table 3. Mann-Whitney U test by gender

	Gender	Mean ± SD	Mann-Whitney U	p
mAs	male	35.31 ± 12.84	1902.00	0.613
	female	37.22 ± 14.36		
BMD	male	0.96 ± 0.24	1546.00	0.049
	female	2.64 ± 7.93		
T-score	male	-0.74 ± 1.33	1512.00	0.035
	female	-1.30 ± 1.37		
BMI	male	23.80 ± 3.46	1983.00	0.891
	female	24.13 ± 4.20		

SD; standard deviation

In the results of the Kruskal-Wallis test according to age group, there were significant results such as x^2=10.03 in BMD and x2=19.07 in T-score except for mAs and BMI. In the results of the post-test, the age group in their 40s or younger and the group in their 50s showed higher BMD and T-score than the age group in their 60s and the group in their 70s or older (Table 4).

Table 4. Kruskal-Wallis H test by age group

Variable	Ages	Mean ± SD	x^2	p	Post-hoc
mAs	Under 49 years	37.72 ± 15.09	0.53	0.91	N/A
	50 ~ 59 years	36.44 ± 14.54			
	60 ~ 69	36.36 ±			

	years	16.89			
	Over 70 years	37.11 ± 11.94			
BMD	Under 49 years[a]	2.48 ± 7.72	10.03	0.02	b < a
	50 ~ 59 years[a]	1.31 ± 2.42			
	60 ~ 69 years[b]	1.85 ± 4.50			
	Over 70 years[b]	3.06 ± 9.54			
T-score	Under 49 years[a]	-0.50 ± 1.81	19.07	< 0.001	b < a
	50 ~ 59 years[a]	-0.67 ± 1.25			
	60 ~ 69 years[b]	-1.44 ± 0.95			
	Over 70 years[b]	-1.58 ± 1.31			
BMI	Under 49 years	22.73 ± 4.15	6.01	0.11	N/A
	50 ~ 59 years	24.21 ± 3.95			
	60 ~ 69 years	25.03 ± 3.66			
	Over 70 years	23.95 ± 4.26			

SD; standard deviation

In the results of the Spearman's rank correlation analysis, the correlation coefficient of mAs and BMI was 0.275. The correlation was significant in the level of 0.01, which showed the positive correlation. On the other hand, both BMD and T-score had no correlations with mAs (Table 5).

Table 5. Spearman's Rank Correlation Analysis

	1	2	3	4
mAs	1			
BMD	-0.077	1		
T-score	-0.004	0.851**	1	
BMI	0.275**	0.215**	0.163*	1

*: Correlation is significant at the 0.05 level, **: Correlation is significant at the 0.01 level.

In the results of the multiple regression analysis by setting up mAs as a dependent variable and BMD, T-score, and BMI as independent variables, only BMI had effects on the dependent variable, and the regression equation is shown as Eq. (1).

$$mAs(y)=5.344-0.258(BMD)-0.184(T\text{-}Score)+1.320(BMI) \quad (1)$$

The coefficient of determination was 0.155, and the adjusted coefficient of determination was 0.140. The Durbin-Watson was 1.702, so there were no problems with autocorrelation (Table 6).

Table 6. Multiple Regression Analysis

	B	SE	β	t	p
constant	5.344	6.420		0.832	0.406
BMD	-0.258	0.141	-0.132	-1.835	0.068
T-score	-0.184	0.751	-0.018	-0.245	0.807
BMI	1.320	0.254	0.380	5.199	< 0.001
R= 0.394, R^2= 0.155, Adj R^2= 0.140, F=10.050, p<0.001, Durbin-Watson= 1.702					

Dependent variable= mAs

Discussion

Even though the diagnostic X-ray uses the low dose, it could have harmful effects on human body, so many international organizations including ICRP are making active efforts for the reduction of exposure dose in patients (12, 13). In case of radiography, many factors could have effects on patient dose. Such factors could be largely classified into effects by patients, effects by radiography equipment, and effects by radiography condition. Among them, the factor affecting the dose by patients includes the sex, height, weight, and exposed part of patients (14). And the bone mineral density test is a representative test method including such factors.

The bone mineral density could be measured by diverse methods such as DEXA, quantitative ultrasound (QUS) and quantitative computed tomography (QCT) (15). This study examined differences in dose according to sex, age, BMD, and BMI, targeting total 168 patients who received the lumbar spine X-ray examination within four months after receiving the lumbar spine bone mineral density test through DEXA. According to sex, the value of mAs and the value of BMD did not show statistically significant results while both T-score and BMI showed significant results. According to age group, the values of mAs and BMI did not show significant results while both T-score and BMD showed significant results. Therefore, there were no statistical differences in mAs according to sex and age.

T-score is calculated by the value of BMD in younger age group. However, in case when measuring the bone mineral density through T-score, it could be changed depending on the measurement method or manufacturer's model, so the T-score did not accord. The discordance of T-score could be different in bone loss rate according to the measured part, or the bone mineral density could be changed. Also, the standard of T-score is the standard value on the basis of white women. Therefore, if the standard more suitable for Asian people is established for analysis, the correlation with mAs could be understood more accurately. The BMI and mAs showed the significantly positive correlation through the Spearman's rank correlation analysis, which means if the BMI of patients could be learnt in advance, the value of mAs could be inferred when setting up the exposure condition. This study aimed to analyze the effects of sex, age, and bone mineral density of patients on dose, and also to draw the regression equation for the reduction of exposure in patients.

In the results of the multiple regression analysis, only the BMI showed the causality with mAs while the BMD and T-score did not have significant causality with dose. Also, the drawn regression equation showed when the BMI increased by 1, the dose also increased by 1.320 mAs. The novice radiological technologists feel difficult to manually set up the condition of dose. As they naturally prefer the use of AEC, they could potentially apply unnecessary dose to patients. However, if the BMI included in the bone mineral density test is used, the optimum dose for representing the high-quality image could be inferred. However, there are several limitations of this study such as this study could not consider the waist measurement which was generally one of the causes for the increase of mAs in the x-ray radiography using the AEC system, and this study did not additionally divide the case that could change the exposure condition such as the image of patients who received the spinal surgery when using the exposed data of patients.

Conclusion

In conclusion, the BMI formed the linear causality with medical exposure of patients. Therefore, if this is used as a tool for calculating the dose by the novice radiological technologists who have just started their radiographic work, it would be possible to reduce the unnecessary exposure of patients. Furthermore, if a prospective study is conducted by collecting the large-scale data using the results of this study as the basic data, it would be helpful for establishing the national diagnostic reference level.

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