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ORIGINAL ARTICLE

Scan Mode Performance of Dual Energy X-ray Absorptiometry Bone Densitometer

SK Yu,[1] KM Ma,[2] SK Cheung[2]

[1]*Medical Physics Division, and* [2] *Department of Nuclear Medicine, Tuen Mun Hospital, Hong Kong*

ABSTRACT

Objective: *A commercially available dual energy X-ray absorptiometry scanner normally provides more than 1 scan mode. The differences between scan modes affect scan time, received radiation dose, and quality of the scan image. A phantom study was performed to evaluate the performance of different scan modes for anterior-posterior spine scan.*

Patients and Methods: *To measure the entrance skin exposure, an ionization chamber was placed on the scanning table in the central region. For a QDR Delphi dual energy X-ray absorptiometry scanner, 4 scan modes were available for spine study.*

Results: *The fastest scan mode, turbo mode, was found to produce underestimated results for total area of the vertebrae (~1%), bone mineral content (~7%), and bone mineral density (~6%). In contrast, the slowest scan mode, high definition mode, was found to produce overestimated bone mineral content (~3%) and bone mineral density (~2%). The results from the default fast array scan mode and the remaining array scan mode were found to be accurate and no significant difference was found between them.*

Conclusion: *Since the fast array scan mode required 50% less scan time and the measured entrance skin dose was also approximately 50% less than the array scan mode, the fast array mode is considered to be the choice for routine clinical spine studies. The turbo scan mode should only be used as an aid in positioning the patient prior to performing a scan.*

Key Words: *Bone density, Scan*

INTRODUCTION

Dual energy X-ray absorptiometry (DXA) is an accurate, precise, and non-invasive method for bone mineral density (BMD) measurement.[1-3] Early DXA systems such as the Hologic QDR-1000[4] and Lunar DPX[5] that use a pencil beam linked to a single detector, scanning the spine or hip, takes 5 to 10 minutes. The advent of the latest fan beam systems using high density solid-state multi-detector array technology has brought improvements in image quality and greatly reduced scanning times to as little as 30 seconds.[6]

Nowadays, commercially available DXA scanners are equipped with more than one choice of scan mode.[7-9] At the Tuen Mun Hospital, a newly installed fan beam multi-detector DXA scanner (QDR-Delphi, Hologic, Bedford, USA) provides 4 choices of scan mode for routine spine scanning. There are differences between scan modes for scan time and X-ray aperture width, and so on. Thus, the overall performance of the machine is, at least theoretically, affected by the choice of the scan mode.

Since the potential for reducing scan times and radiation dose to patients is always appreciated, we have evaluated the performance of the 4 scan modes available for routine spine examination. The purpose is to quantify the differences in performance between the scan modes so that scan time and dose can be minimised while the image quality for scan analysis is maximised.

PATIENTS AND METHODS

The QDR-Delphi DXA scanner (Hologic, Bedford, USA) employed in this study has 4 scan modes available: turbo, fast array, array, and high definition. The

Correspondence: Mr SK Yu, Medical Physics Unit, Tuen Mun Hospital, New Territories, Hong Kong.
Tel: (852) 2468 5484; Fax: (852) 2455 7449

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performance of scan modes was evaluated by comparing the scan time, patient entrance skin dose, and the measured bone mineral density for AP lumbar spine scans.

An anthropomorphic spine phantom (Hologic, Bedford, USA) with specifications (mean ± standard deviation) of total area of 4 vertebrae (area = 53.138 ± 0.220 cm^2), total bone mineral content (BMC = 54.341 ± 0.192 g), and bone mineral density (BMD = 1.023 ± 0.003 g/cm^2) was used as a gold standard for the evaluation. Note that the phantom was originally designed for daily quality assurance of the accuracy and precision of the DXA system. Fifty scans were performed for each scan mode and the scan length was kept unchanged to the default value of 20.6 cm. The phantom was not repositioned between the scans and a single operator analysed all the scans using the standard protocol with auto-defined region of interest feature as recommended by the manufacturer (Hologic QDR software for windows Version 11.2, Bedford, USA).

The measured area, BMC, and BMD were compared with the phantom specifications, and a 2-tailed z-test[10] was used to evaluate their accuracy. The precision of the measured results for each scan mode was represented by coefficient of variation. This was calculated by dividing the standard deviation by the mean for a set of data and it was expressed as a percentage by multiplying by 100. Using unpaired t-test, the measured BMD results obtained from the fast array mode (the default scan mode) were compared with those from other scan modes.

For entrance skin dose assessment, an 180 cc ionization chamber (MDH2026, RadCal Corporation, Monrovia, USA) was positioned in the central region of the scanning area and on the X-ray entrance surface of the phantom. The measurement was done on each scanning mode with parameters set to the same as in the spine phantom measurement.

RESULTS

The scan parameters and the measured entrance skin dose are listed in Table 1. The scan time and scan lines were approximately doubled when the scan mode was changed from turbo to fast array, fast array to array, or

Table 1. Scan parameters and measured entrance skin dose.

	Scan mode			
	Turbo	Fast array	Array	High definition
Scan length (cm)	20.6	20.6	20.6	20.6
Scan width (cm)	11.4	11.4	11.4	11.4
Line spacing (cm)	0.1008	0.1008	0.1008	0.1008
Point resolution (cm)	0.0901	0.0901	0.0901	0.0901
Collimation (cm x cm)	6.10 x 0.10	6.10 x 0.10	6.10 x 0.10	6.10 x 0.10
Tube potential (kV)	140/100	140/100	140/100	140/100
Average mA	2.5	2.5	2.5	2.5
Scan time (s)	25	49	98	195
Scan lines	101	201	403	807
Frequency (Hz)	50	50	50	50
Aperture width (mm)	2	1	1	0.5
Measured entrance skin dose (mGy)	50.6	100.7	200.3	169.5

Table 2. Comparison of accuracy and precision between turbo mode and fast array mode.

	Turbo			Fast array		
	Area (cm^2)	BMC (g)	BMD (g/cm^2)	Area (cm^2)	BMC (g)	BMD (g/cm^2)
Mean	52.53	50.43	0.960	53.43	54.57	1.021
Standard deviation	0.26	0.32	0.005	0.22	0.28	0.004
Coefficient of variation (%)	0.50	0.64	0.51	0.41	0.52	0.36
99% Confidence intervals	± 0.67	± 0.83	± 0.01	± 0.57	± 0.72	± 0.010
Average absolute deviation from phantom mean	0.61	3.91	0.063	0.31	0.30	0.003
Range of absolute deviation from phantom mean (minimum, maximum)	0.05, 1.44	3.28, 4.75	0.052, 0.072	0.00, 0.75	0.00, 0.85	0.000, 0.012
Inaccurate data*	28/50	50/50	50/50	5/50	8/50	2/50
p Value from 2-tailed z-test†	0.006	0.003	0.003	0.184	0.234	0.503
p Value from unpaired t-test‡	8×10^{-34}	3×10^{-54}	9×10^{-86}			

* Data was considered accurate if their values were within 99% confidence limits.
† Compared with the phantom mean with known standard deviation.
‡ Compared with results from fast array mode since it was the default mode for scanning.
Abbreviations: BMC = bone mineral content; BMD = bone mineral density.

Table 3. Comparison of accuracy and precision between array mode and fast array mode.

	Array			Fast array		
	Area (cm^2)	BMC (g)	BMD (g/cm^2)	Area (cm^2)	BMC (g)	BMD (g/cm^2)
Mean	53.42	54.62	1.022	53.43	54.57	1.021
Standard deviation	0.21	0.26	0.004	0.22	0.28	0.004
Coefficient of variation (%)	0.38	0.47	0.36	0.41	0.52	0.36
99% Confidence intervals	± 0.54	± 0.67	± 0.010	± 0.57	± 0.72	± 0.010
Average absolute deviation from phantom mean	0.31	0.32	0.003	0.31	0.30	0.003
Range of absolute deviation from phantom mean (minimum, maximum)	0.01, 0.71	0.00, 0.88	0.00, 0.007	0.00, 0.75	0.00, 0.85	0.000, 0.012
Inaccurate data*	4/50	11/50	0/50	5/50	8/50	2/50
p Value from 2-tailed z-test†	0.201	0.147	0.741	0.184	0.234	0.503
p Value from unpaired t-test‡	0.9	0.4	0.2			

* Data was considered accurate if their values were within 99% confidence limits.
† Compared with the phantom mean with known standard deviation.
‡ Compared with results from fast array mode since it was the default mode for scanning.
Abbreviations: BMC = bone mineral content; BMD = bone mineral density.

Table 4. Comparison of accuracy and precision between high definition mode and fast array mode.

	High definition			Fast array		
	Area (cm^2)	BMC (g)	BMD (g/cm^2)	Area (cm^2)	BMC (g)	BMD (g/cm^2)
Mean	53.37	55.72	1.044	53.43	54.57	1.021
Standard deviation	0.26	0.28	0.003	0.22	0.28	0.004
Coefficient of variation (%)	0.50	0.51	0.31	0.41	0.52	0.36
99% Confidence intervals	± 0.67	± 0.72	± 0.008	± 0.57	± 0.72	± 0.010
Average absolute deviation from phantom mean	0.29	1.37	0.021	0.31	0.30	0.003
Range of absolute deviation from phantom mean (minimum, maximum)	0.01, 0.77	0.70, 1.89	0.014, 0.031	0.00, 0.75	0.00, 0.85	0.000, 0.012
Inaccurate data*	7/50	50/50	50/50	5/50	8/50	2/50
p Value from 2-tailed z-test†	0.294	0.003	0.003	0.184	0.234	0.503
p Value from unpaired t-test‡	0.2	1×10^{-36}	7×10^{-54}			

* Data was considered accurate if their values were within 99% confidence limits.
† Compared with the phantom mean with known standard deviation.
‡ Compared with results from fast array mode since it was the default mode for scanning.
Abbreviations: BMC = bone mineral content; BMD = bone mineral density.

array to high definition. However, the measured entrance skin dose was more complicated and did not follow this 'doubling' trend. This was mainly due to differences in the X-ray aperture size and in the area that had been double-exposed. The entrance skin dose was increased by approximately double for scan mode changed from turbo to fast array or fast array to array, then it decreased by approximately 15% from array to high definition. The spatial resolution, also called point resolution in the QDR machine, was not affected by the scan mode since it is determined by the physical size of the array detectors.

The measured area, BMC, and BMD obtained from different scan modes are listed in Tables 2, 3, and 4. The precision of measurements from all scan modes was below 1%. However, the turbo mode produced inaccurate results ($p < 0.05$ from z-test) that were approximately 6% lower in BMD, 1% lower in area, and 7% lower in BMC. The fast array mode and array mode produced accurate results ($p > 0.05$ from z-test), and there were no statistically significant differences between the results ($p > 0.05$ for area, BMC, and BMD from t-test). In contrast, a statistically significant difference was observed between the results from the fast array mode and the turbo mode ($p < 0.05$ for area, BMC, and BMD from t-test). Similarly, some of the results from the high definition mode were inaccurate ($p > 0.05$ for area and $p < 0.05$ for BMC and BMD from z-test) and statistically different ($p > 0.05$ for area and $p < 0.05$ for BMC and BMD from t-test) from those obtained by the fast array mode.

DISCUSSION

Development of DXA scanners with multidetector array technology has resulted in greatly shortened scanning times with high quality images. For the QDR-Delphi DXA scanner, a choice of 4 scan speeds for routine spine examination are available. However, only a small amount of information about their performance has been published and no comparison between the scan modes has been made. The purpose of this investigation was to evaluate the scan modes so that selection of scan mode for routine clinical studies of the spine could be rationally made.

In a previous study, Patel et al compared QDR-4500 BMD scans of the spine (L1-L4) of 151 female patients acquired using turbo mode and fast mode.[11] These researchers found that the measured bone mineral density (BMD) obtained from the 2 scan modes was linear over a wide range. For turbo mode, the in vivo short-term precision was 1.3% and it was poorer than the values of 0.7% to 1.0% for the default mode reported from other researchers.[6,12]

In this in vitro study, all scan modes were found to provide precise BMD measurement and all the coefficients of variation were less than 1%. Consistent with the study of Patel et al,[11] the precision for turbo mode (0.51%) was poorer than the default mode (fast array mode, 0.36%). Turbo scan mode was found to produce inaccurate results that were approximately 6% lower in measured BMD, 1% lower in measured total area of vertebrae, and 7% lower in measured BMC. These results from turbo mode were statistically significantly different to those from the fast array mode. The difference of 0.061 g/cm^2 between turbo mode and fast array mode or difference of 0.063 g/cm^2 between turbo mode from the phantom mean is clinically significant. This can be compared to the standard deviation of other reference database (one standard deviation of AP spine for white females in the USA from the manufacturer reference database is 0.11 g/cm^2[2,13]). Thus, turbo mode should not be used for routine clinical studies except as an aid in positioning the patient prior to performing a scan. Fast array mode required 50% and 25% of the scan time in array mode and high definition mode, respectively. In this study, the measured entrance skin dose from the fast array mode also showed approximately 50% less than the array mode and 70% less than the high definition mode. Moreover, the high definition mode produced inaccurate measurement of BMC and BMD (~3% higher for BMC and ~2% higher for BMD). Thus, it was concluded that the fast array mode was the best choice for routine clinical spine studies.

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