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ORIGINAL ARTICLE

The effect of room temperature on dual-energy X-ray absorptiometry

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Abstract There has been little published data on the effects of temperature on the performance of dual-energy X-ray absorptiometry (DXA) machines. We examined the effect of changes in ambient room temperature on the performance of three DXA scanners (DPXL, Expert-XL and Prodigy). The study involved repeat measurements of bone mineral density (BMD) using three different spine phantoms scanned at different ambient room temperatures, both before and after calibration procedures. The calibration or quality assurance (QA) scan calibrates the scanner, adjusting for the ambient room temperature at the time of calibration. There was a moderate correlation between change in temperature and change in BMD measured prior to recalibration for the Expert-XL ($r = 0.58$) during normal clinical scanning conditions. There was no observed change in phantom BMD with change in temperature measured using the DXPL or Prodigy. After temperature change, without repeat calibration measurements, there was a strong correlation between temperature change and change in BMD measured using the Expert-XL ($r = 0.96$, $p < 0.001$). From the regression equation, a change of 2.5 °C could alter the calculated BMD result measured by the Expert-XL by 1.5%, which would significantly affect the precision of the DXA system. There was no significant correlation between temperature and BMD in the DXPL or Prodigy. The observed differences between the densitometers and the effect of temperature change are most likely due to the differing types of detector systems used. Operators must be made aware that solid state detectors of the sort used in the Expert-XL (charge-coupled devices, CCDs) are significantly affected by changes in ambient room temperature.

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Introduction

Following the introduction of dual-energy X-ray absorptiometry (DXA) there have been a number of technological changes which have improved scanning time, resolution and potentially precision [1, 2, 3]. One of the most important of the more recent developments has been the advances in the methodology for quantitative X-ray detection used in the fan-beam and new generation Lunar Prodigy narrow-angle fan-beam densitometers. Older Fan beam scanners use photodiodes for X-ray quantitation. A photodiode converts light, generated by the interaction of an X-ray with a scintillating material [4], into an electronic signal, replacing the older photomultiplier tube (PM tube) system used in the previous generation of DXA machines. The Prodigy employs direct digital detectors which do not use scintillation.

The effect of temperature on the performance of X-ray detectors, and hence on calculated bone mineral density (BMD), is accounted for in some DXA systems [5]. In the Lunar Expert-XL (Lunar, Madison, WI) a temperature correction factor is determined from ambient room temperature measurements performed at the time of daily calibration. This correction factor, generated by the calibration procedure, is applied to all subsequent patient BMD quantitation, irrespective of any change in ambient room temperature less than a preset limit (±3 °C), until a new calibration procedure is performed. Potentially a change in ambient temperature in a DXA laboratory during the day, without a re-calibration and hence without a corresponding change in correction factor, may compromise the precision of the DXA machine.

The magnitude of BMD change following temperature change within the DXA clinical environment has not been previously reported. We examined the magnitude of change of BMD in scans of a spine phantom with change in temperature, using three separate DXA instruments.

Materials and methods

The in vitro precision of the DXA scanners in our institution used in this study, expressed as the coefficient of variation, is 0.46%, 0.35% and 0.20%, respectively, for the Expert-XL, DPXL and Prodigy, respectively. The study was comprised of three experiments. For both experiments 1 and 2 the interval of time after a QA procedure, and before the next QA procedure, during which scanning of the phantom was performed, is referred to as a calibration period. In experiments 1 and 2 the change in phantom BMD measurements, obtained at two successive time points within a single calibration period, was compared with the observed corresponding temperature change. Temperature was measured using a standard room thermometer (coefficient of variation 1%).

Experiment 1

In the first experiment the Lunar Expert-XL (Lunar, Madison, WI) was used to obtain multiple scans of a Bona Fide spine phantom (Madison, WI), during a period when the air conditioning system was not operational. The Bona Fide spine phantom (BFP) consists of a bone-equivalent material (L1–L4), with varying BMD levels, embedded in a tissue-equivalent resin. The BFP is used in our laboratory for daily quality control of the Expert-XL, to monitor the long-term precision of the densitometer. The BFP has a long-term established mean of 1.142 g/cm^2 with the Expert-XL used in this study. All scans of the BFP were obtained using the same scanning parameters.

Each day of the study the Expert-XL was calibrated in the morning using the recommended daily calibration procedure (Lunar "Quality Assurance" or "QA") which adjusts for the "signal noise" levels from the detector at different temperatures. The temperature of the room was recorded at the time of the morning QA. The BFP was subsequently scanned once at various time points on 14 separate days, before and after, repeating the QA procedure. The temperature at the time of each BFP scan was recorded.

Experiment 2

In the second experiment the densitometry laboratory was slowly heated over several hours. At each 0.5 °C change the BFP was scanned once using the Expert-XL, before and after a QA procedure (four × 2 measurements). A similar protocol was followed with a DPXL machine (Lunar, Madison, WI), situated within the same laboratory, which was used to scan a Hologic Spine phantom (Hologic, Waltham, MA) over the same temperature range, before and after QA procedures performed at approximately each 0.5 °C increment. The Hologic spine phantom consists of semi-anthropomorphic vertebrae (L1–L4) suspended within a tissue-equivalent resin, and is used for long-term monitoring of the DPXL. In our laboratory the Hologic spine phantom has an established mean of 1.212 g/cm^2 measured using the DPXL.

Experiment 3

In the third experiment the densitometry laboratory was heated slowly over several hours and single scans of the phantoms were performed over a range of temperatures. A single daily calibration (QA) procedure was performed before heating commenced but was not repeated during the remainder of the experiment. The DXA machines and the phantoms used were the same as for experiment 2 of this study. The experiment was also repeated using a Lunar Prodigy (Lunar, Madison, WI), situated in another laboratory, using the Lunar bar spine phantom, which consists of an aluminum bar surrounded by a water bath. As for the experiment using the Expert-XL and the DPXL, BMD was monitored at approximately each 0.5 °C increment in temperature.

Results

The range in temperature over several days in experiment 1 was 19.0 °C to 23.6 °C. The greatest observed change in temperature during any single calibration period was 2 °C. There was a moderate negative correlation between the change in room temperature during a single calibration period and the change in phantom BMD (Fig. 1; $r = 0.58$; $p < 0.05$). These data were supported by the results of experiment 2, performed under controlled conditions (Fig. 1), although there were too few observations by themselves to achieve statistical significance. After each calibration QA procedure the BMD results for the BFP returned to a value within the expected range for both experiment 1 (Fig. 2) and experiment 2 (Table 1). There was no significant difference in phantom BMD, measured using the DPXL, at different temperatures in experiment 2 (Table 1).

The temperature change for experiment 3 was approximately 4 °C over approximately 2 h. The results demonstrated a strong negative correlation between temperature and BFP BMD for the Expert-XL (Fig. 3; $r = 0.96$; $p < 0.001$). There was no significant correlation

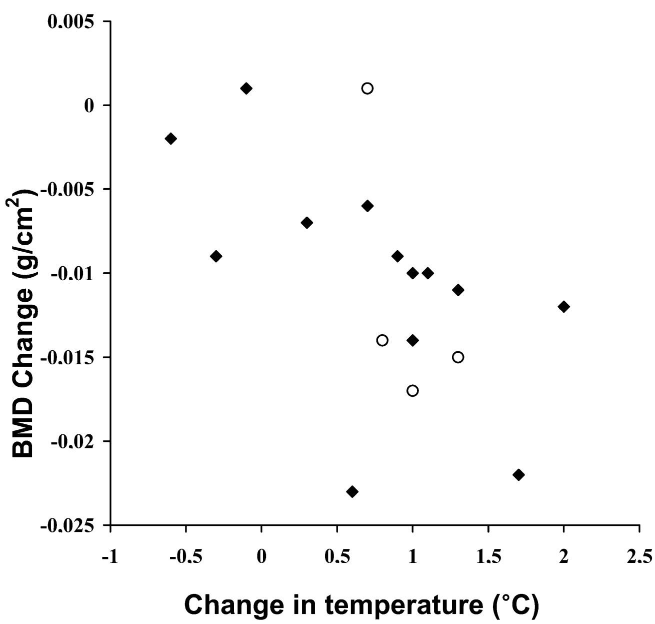

Fig. 1 Change in phantom bone mineral density (BMD) versus change in ambient room temperature in a single calibration period, measured using the Expert-XL. *Filled diamonds*, experiment 1; *open circles*, experiment 2. One scan was performed at each point

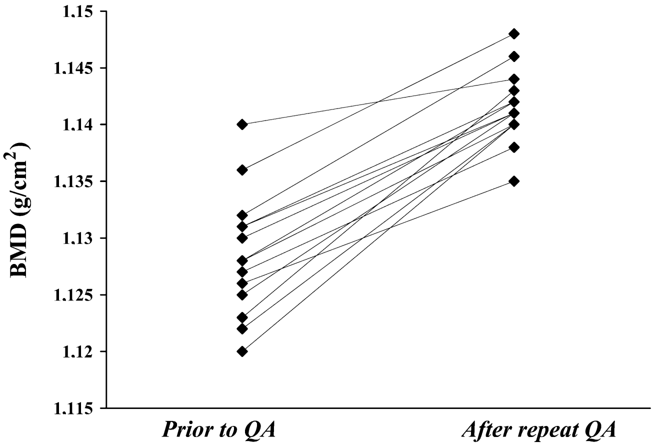

Fig. 2 Bona Fide phantom (BFP) bone mineral density (BMD) measurements following a change in temperature prior to and after a Quality Assurance (calibration, QA) procedure, using the Expert-XL (experiment 1). One scan was performed at each point

Table 1 Mean phantom BMD (g/cm^2) after temperature change and after repeat Quality Assurance (calibration) procedures for experiment 1 and experiment 2 (14×2 measurements experiment 1, 4×2 measurements experiment 2)

	Mean BMD after temperature change (SD)	Mean BMD after QA (SD)	Established mean (SD)
Expert-XL experiment 1	1.129 (0.006)	1.140 (0.004)	1.142 (0.006)
Expert-XL experiment 2	1.133 (0.006)	1.147 (0.005)	1.142 (0.006)
DPXL experiment 2	1.219 (0.007)	1.217 (0.005)	1.212 (0.004)

between change in temperature and BMD measured using the DPXL or Prodigy (Fig. 3).

Discussion

The results of this study confirm a significant effect of ambient room temperature on measured BMD in some DXA scanners. The effect is, however, not observed in all DXA scanners, most likely due to the different X-ray detector systems employed. Most DXA scanners use a scintillating material in their detector systems, which emit light dependent on the amount and energy of X-rays detected. The light is subsequently detected and converted to an electrical signal, using one of a number of devices. The older DXA scanners, such as the DPXL, use a photomultiplier tube assembly, which is relatively temperature insensitive [4], explaining the stability of BMD measured using the DPXL at different temperatures. The newer generation fan-beam scanners, however, employ different devices to convert the light generated by the scintillator into an electrical signal. CCDs are one type of system used for light conversion in some fan-beam DXA machines, including the

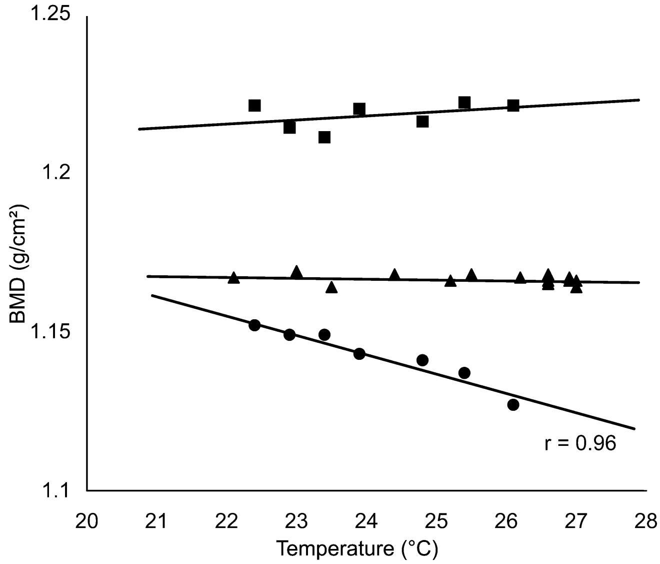

Fig. 3 Change in phantom BMD versus temperature change within a single calibration period (experiment 3) for the Expert-XL (*circles*; Bona Fide phantom), the DPXL (*squares*; Hologic phantom) and the Prodigy (*triangles*; Lunar bar phantom). One scan was performed at each point

ExpertXL. CCDs suffer from "dark current", which is a term used to describe the unwanted electrical charge which occurs naturally within CCDs when they operate at a temperature above zero [6]. This dark current creates "noise" or an unwanted electrical signal within the detector. The magnitude of the dark current has a strong positive correlation with the operating temperature [6], and hence may provide an explanation for the significant correlation between temperature and phantom BMD observed in this study in the Lunar Expert-XL.

The Expert-XL system uses the QA calibration procedure to measure the amount of dark current, at the specific ambient operating temperature, and correct for the "noise" generated [5]. The generated correction factor remains constant for all scans performed until a new QA procedure is performed, irrespective of variations in ambient temperature, within a ± 3 °C window. Our results confirm that temperature changes of a range often observed will result in differences in measured phantom BMD which exceed the reported in vitro precision error [7], but a repeat QA procedure will return the BMD results from the Expert-XL to an acceptable operating range.

The Lunar Expert-XL was designed to prompt an operator to perform a modified calibration procedure, sometimes referred to as a "Quick Air Scan", if the change in temperature since the last QA measurement is greater than 3 °C [5]. However, the current study has demonstrated that temperature changes of less than 3 °C can have a significant impact on measured BMD. The regression equation obtained from experiment 3 demonstrated that a change of 2.5 °C, which would not trigger a prompt from the scanner for recalibration, would cause a BMD change of approximately 1.5%.

This change in BMD with change in temperature in DXA scanners using CCDs, while not large, potentially could decrease precision and increase the minimum significant change in BMD in a clinical setting. While the Expert-XL alerts the technologist to the need for a repeat QA with a 3 °C or greater change in ambient room temperature, precision is reduced before this degree of temperature change occurs. All technologists should be aware that a constant room temperature will minimize precision error of DXA instruments utilizing CCDs. This may require the installation and use of air conditioning systems even in temperate climates.

The most recent generation of arrow angle fan-beam DXA machines, the Lunar Prodigy, do not use CCDs but employ direct digital cadmium-zinc-telluride to convert the x-ray energy directly into the required electrical signal. The stability of these detectors over the usual operating temperature is confirmed by the results of the current study, which did not show any change in phantom BMD measured by the Prodigy at different temperatures. Such DXA systems are hence likely to have better precision in laboratories that experience fluctuations in temperature than DXA systems using CCDs. A weakness of this study is that the results were not confirmed on Hologic or other makes of DXA scanners apart from Lunar. The physical properties of the detectors, however, are independent of the manufacturer, and while verification using other scanners is warranted, the results are likely to be dependent primarily on the detector type used by particular instruments.

A possible mechanism by which temperature change in the range tested could affect the measurement of areal density from the interaction of X-rays with the phantom material, is that expansion of tissues with increasing temperature could theoretically result in an apparent decrease in areal density. This, however, would not explain the results as the linear coefficient of thermal expansion of the phantom materials [8] indicates that a temperature change of the magnitude used in the experiments would result in a less than 0.01% change in areal density.

In conclusion, operators of densitometry scanners using CCDs need to be aware of the need for constant room temperature throughout the day. Repeat QA procedures should be performed to recalibrate the scanner if the ambient room temperature alters significantly from the temperature at the time of the previous QA measurement.

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