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Original Article

Discrepancies in Normative Data between Lunar and Hologic DXA Systems

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Abstract. Many studies have shown the high correlation between Lunar and Hologic DXA bone mineral density (BMD) measurements despite differences in absolute calibration. However, in clinical practice, raw BMD values (in g/cm^2) are not normally used for assessing skeletal status and fracture risk. Instead, the BMD values are expressed in terms of the number of standard deviations above or below the young normal value (commonly referred to as the *T*-score). If the normative populations of the various systems are consistent, the standard deviation scores should also be consistent. For this reason, the World Health Organization (WHO) recently established diagnostic criteria for osteoporosis based on *T*-scores and not BMD. However, few studies have compared the instruments in terms of their standard deviation scores. In this study, we used linear regression to compare *T*-scores in 83 women at L1–4 and 120 women at the femoral neck obtained on a Lunar DPX and a Hologic QDR-1000/W system. Patient BMD and *T*-score measurements were highly correlated between the two systems ($r>0.95$). No clinically significant difference in L1–4 *T*-scores was seen (less than 0.1 SD). However, linear regression analysis confirmed a systematic difference of 0.9 SD between the femoral neck T-scores. This discrepancy is caused by: (1) differences in the normal populations, and (2) differences in statistical models used to determine the young normal mean and standard deviation. In an attempt to correct the discrepancy, the female young normal mean and standard deviation were recalculated for the femoral neck using published epidemiological data from NHANES and existing DXA cross-calibration equations. The Hologic young normal value (mean ± SD) was redefined as 0.85 ± 0.11 g/cm^2, while the Lunar value was redefined as 1.00 ± 0.11 g/cm^2. When the femoral neck *T*-scores for the study population were recalculated on the basis of these new values, the results were equivalent between manufacturers, effectively eliminating the discrepancy. However, the revised values should be confirmed by additional measurements in young normal adults.

Keywords: Diagnosis; DXA; Hip fracture; Normative data; Osteoporosis

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Introduction

Osteoporosis has been defined by two recent consensus development conferences as "a disease characterized by low bone mass and microarchitectural deterioration of bone tissue, leading to enhanced bone fragility and a consequent increase in fracture risk" [1,2]. While having conceptual merit, the practical application of this definition requires the establishment of specific criteria to be used in a clinical setting. In response to this need, the World Health Organization (WHO) has proposed a set of criteria for the diagnosis of osteoporosis in adult women [3]. These criteria define the following categories based on the measured bone mineral density (BMD) or bone mineral content (BMC) at any skeletal site:

Normal: BMD or BMC not more than 1 standard deviation (SD) below the young adult mean.

Low bone mass (osteopenia): BMD or BMC between 1 and 2.5 SD below the young adult mean.

Osteoporosis: BMD or BMC more than 2.5 SD below the young adult mean.

Severe osteoporosis: BMD or BMC more than 2.5 SD below the young adult mean in the presence of one or more fragility fractures.

Each of these definitions depends on the mean young adult value and the standard deviation of the normative population. These parameters in turn are a function of the skeletal site measured and the type of equipment used. Differences in BMD between skeletal sites are expected in the same person due to differential rates of bone loss as well as varying ratios of cortical and trabecular bone. Thus discrepancies in the diagnosis of osteoporosis between different skeletal sites are expected [4,5]. However, comparisons of BMD values at the same skeletal site obtained on two different instruments should be relatively consistent. This is particularly true for dual-energy X-ray absorptiometry (DXA) data, for which correlations between instruments are known to be high [6].

In spite of the reported high correlations, existing studies indicate that even when bone density is expressed as a percentage of young normal, the results obtained on Lunar and Hologic machines may be inconsistent. Pocock et al. [7] compared Lunar and Hologic DXA scanners in a group of 46 women, and found significant differences in the percentage young normal BMD values at the spine and femoral neck. The spinal differences was relatively small (2.0%), while the femoral neck difference was more pronounced (6.2%) [7]. They also found that the Hologic femoral neck values (expressed as a percentage of young normal) were significantly lower than the equivalent Lunar values. Although standard deviation scores were not reported, this result would indicate a potential for Hologic instruments to estimate a higher prevalence of osteoporosis compared with Lunar equipment using the WHO criteria.

In this study, we addressed the question of whether a diagnosis of osteoporosis (as defined by WHO) depends on the type of DXA scanner used. We compared Lunar and Hologic measurements at the spine and proximal femur in a group of women with a wide range of bone mass. BMD values were expressed as the number of standard deviations above or below the mean young adult normal values. We compared the prevalence of osteoporosis in our patient population using the WHO definition (2.5 SD below young normal). On the basis of our results, we suggest appropriate corrections to resolve any potential discrepancy, so that the WHO criteria might be consistently applied to both Lunar and Hologic measurements.

Materials and Methods

As a test of the comparability of the standard deviation scores between scanners, cross-calibration data from a group of women measured in our laboratory on a Lunar DPX and Hologic QDR-1000/W were compared. The L1–4 anteroposterior spine measurements from 83 women (18–86 years of age, average age 60 ± 15 years) and femoral neck measurements from 120 women (24–86 years of age, average age 59 ± 13 years) were obtained on the same day by the same technician. Scans were analyzed by the same technician using standard analysis procedures. The calculated BMD from each scanner was expressed as the number of standard deviations above or below the mean young normal value (commonly referred to as the *T*-score).

For this calculation, it is necessary to know the young normal mean and standard deviation for each skeletal site measured. These are provided in the reference databases supplied with each DXA system (Table 1). Using these young normal values and standard deviations, the *T*-score for each patient is found using the following formula:

$$T\text{-score} = \frac{\text{measured BMD} - \text{young normal BMD})}{\text{standard deviation}}$$

These values are reported on the Hologic and Lunar reports as the "*T*-score" and "Young Adult *Z*-score", respectively. Note that these standard deviation scores do not depend on age, and are a function only of the mean young normal value and the population standard deviation.

Paired *t*-tests were used to assess the significance of the differences between the standard deviation scores obtained at the same skeletal site but on different devices. Using linear regression analysis, the slope and intercept of the standard deviation scores from Hologic versus those from Lunar were calculated. The 95% confidence intervals were also determined. If the devices provide equivalent standard deviation scores, the confidence interval should contain 1.0 for the slope and 0.0 for the intercept. Significant differences indicate that the young normal mean and standard deviation for one or both of the manufacturers require adjustment.

The percentage prevalence of osteoporosis at the spine and femoral neck was determined using the WHO criteria. The percentage agreement between the two systems was calculated as the number of concordant diagnoses (i.e. either osteoporotic or normal) at each

Table 1. Adult female young normal mean bone mineral density (BMD, in g/cm^2) and standard deviation (SD, in g/cm^2) at the L1–4 spine and femoral neck for Hologic and Lunar systems. The ages (years) used to define young normal are given for each system and skeletal site. For the femoral neck, the manufacturer-reported and redefined values based on data from [6] and [8] are given.

	Hologic			Lunar		
	Age	BMD	SD	Age	BMD	SD
L1–4 spine	30	1.047	0.11	20–45	1.180	0.12
Femoral neck						
Reported	22	0.895	0.10	20–45	0.980	0.12
Redefined	20–29	0.85	0.11	20–29	1.00	0.11

skeletal site divided by the total number of subjects measured.

Results

BMD results from the patients studied are shown in Figs 1 and 2. *T*-scores at the spine ranged from −5.4 to 3.1 on Hologic and from −5.2 to 3.1 on Lunar. Mean L1–4 *T*-scores for the entire population were similar (−2.1 for Hologic and −2.0 on Lunar) but statistically different ($p = 0.02$). At the femoral neck, *T*-scores ranged from −5.1 to 0.6 on Hologic and −3.9 to 1.2 on Lunar, with means of −2.4 and −1.5, respectively. By paired *t*-test, this difference was highly significant ($p<0.001$). In Figs 3 and 4, plots of the individual *T*-scores from the patient cross-calibration study are shown. Values were highly correlated at both the spine ($r=0.99$) and the femoral neck ($r=0.95$). Regression equations were calculated as:

L1–4 spine: Hologic = 1.001 (Lunar) − 0.049
Femoral neck: Hologic = 1.017 (Lunar) − 0.905

The 95% confidence intervals of the slope were 0.97 to 1.03 at the spine and 0.96 to 1.08 at the femoral neck. For the intercept, the 95% confidence intervals extended from −0.13 to 0.03 at the spine and −1.01 to −0.80 at the femoral neck. Of the regression parameters, only the femoral neck intercept fell outside the 95% confidence range. This indicates that the difference between Lunar and Hologic femoral neck standard

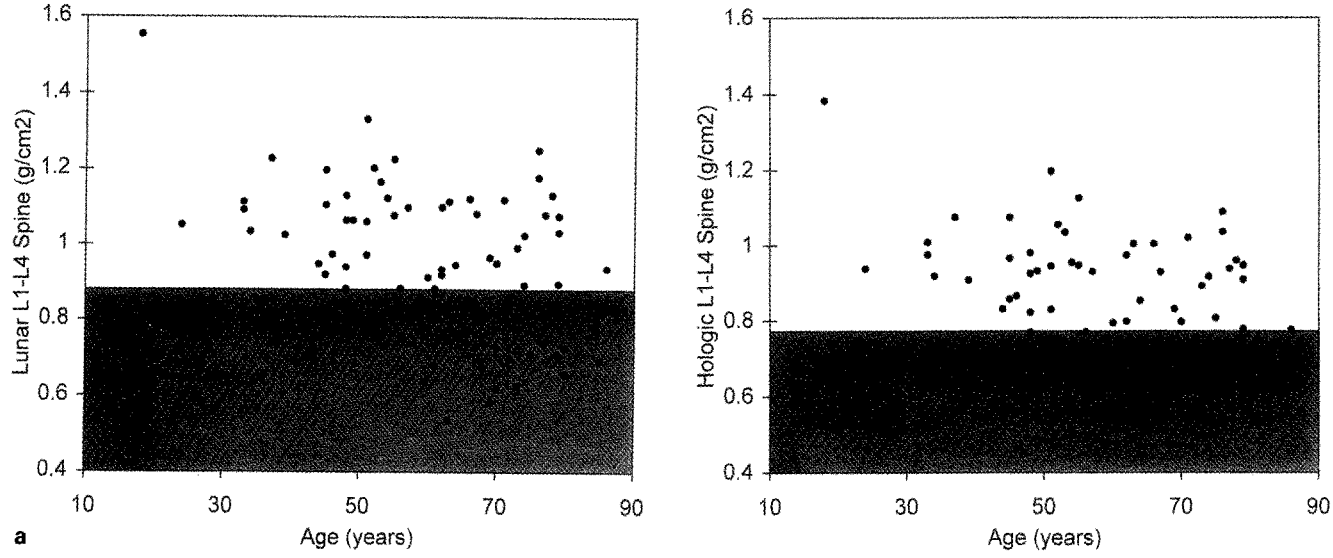

Fig. 1. BMD of the spine as a function of age for the 83 women in the study, using both Lunar (**a**) and Hologic (**b**) DXA systems. The *shaded area* represents the WHO definition for osteoporosis of more than 2.5 SD below the young normal mean.

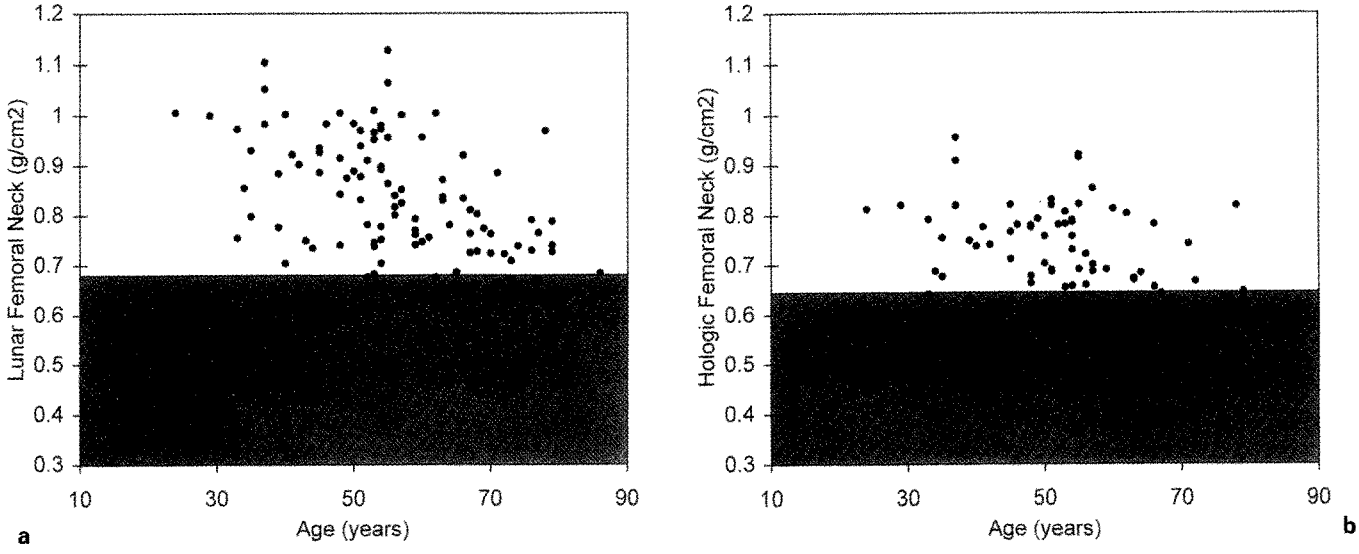

Fig. 2. BMD of the femoral neck as a function of age for the 120 women in the study, using both Lunar (**a**) and Hologic (**b**) DXA systems. The *shaded area* represents the WHO definition for osteoporosis of more than 2.5 SD below the young normal mean.

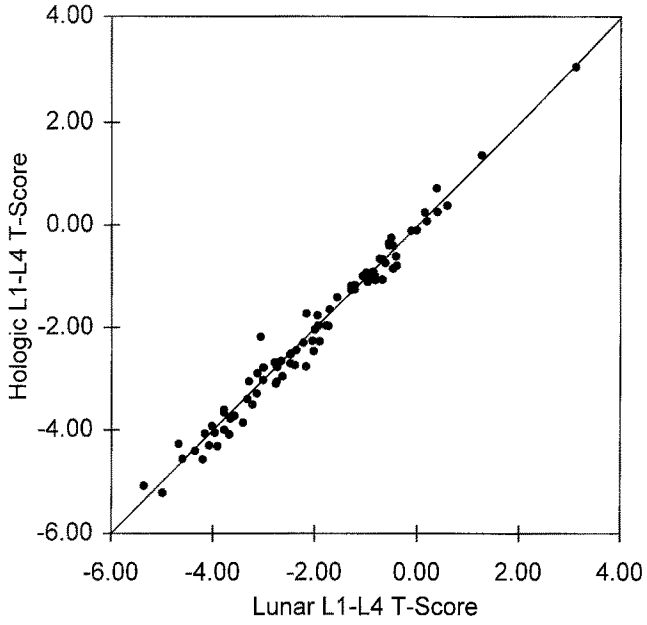

Fig. 3. Results of the cross-calibration measurements at the anteroposterior spine (L1–4) in 83 women measured on a Lunar DPX and Hologic QDR-1000/W. Data are expressed as the number of standard deviations from the mean young adult value for each system (*T*-score). The line of identity is also shown.

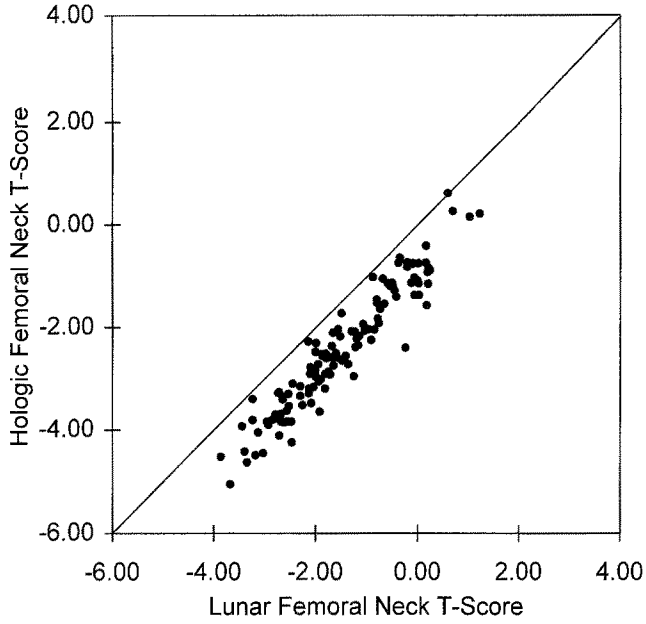

Fig. 4. Results of the cross-calibration measurements at the femoral neck in 120 women measured on a Lunar DPX and Hologic QDR-1000/W. Data are expressed as the number of standard deviations from the mean young adult value for each system (*T*-score). The line of identity is also shown.

deviation scores is due to an offset rather than a multiplicative factor.

To correct for this offset at the femoral neck, it is necessary to adjust the young normal mean and standard deviation. As a basis for this adjustment, the NHANES III database was used, which was collected from three Hologic QDR-1000 densitometers located in mobile examination centers [8]. This study includes a sample of 194 non-Hispanic white women aged 20–29 years. Their femoral neck BMD is reported as 0.849 ± 0.109 g/cm^2, which is lower than the Hologic young normal mean and with a larger standard deviation. Using this value as the redefined young normal mean, the equivalent Lunar value can be calculated from cross-calibration equations published by Genant et al. [6]. For the femoral neck, the equation relating Lunar and Hologic values is

$$\text{Lunar} = 1.013(\text{Hologic}) + 0.142$$

This yields an equivalent Lunar young normal femoral neck BMD of 1.00 g/cm^2. Since the difference between manufacturers was an offset rather than a multiplicative factor, the standard deviation was taken to be equivalent for both Lunar and Hologic instruments at the NHANES value of 0.11 g/cm^2. The original and (in the case of the femoral neck) redefined young normal mean and standard deviation are shown in Table 1. When the femoral neck standard deviation scores of our study population were recalculated using the redefined young normal mean and standard deviation, the results were not statistically different by a paired *t*-test (−1.79 for Hologic, −1.80 for Lunar, p=0.92).

In Table 2, the prevalence of osteoporosis at the spine and femoral neck is given for each scanner type. Also shown as the results using the redefined young normal mean and standard deviation at the femoral neck. While results were similar at the spine, the Hologic system reported more than twice the prevalence at the hip than the Lunar measurements in the same population. However, using the corrected normative values, the percentage prevalence at the neck was in agreement (96%) between the manufacturers.

Table 2. Prevalence of osteoporosis in the female subjects of the study for each scanner type

	Lunar	Hologic	Agreement
L1–4 spine (n=83)	33 (40%)	37 (45%)	77 (93%)
Femoral neck (n=120)			
Reported	27 (23%)	62 (52%)	85 (71%)
Redefined	35 (29%)	34 (28%)	115 (96%)

Osteoporosis is defined as a BMD more than 2.5 SD below the mean young normal value at the measurement site. The percentage of concordant diagnoses (i.e. measurements on both systems either above or below the −2.5 SD criteria) is given. For the femoral neck, results are shown for the manufacturer-reported and redefined standard deviation scores.

Discussion

In this study we have shown that significant differences between Hologic and Lunar DXA systems exist in the reported young normal standard deviation scores (*T*-scores). Although highly correlated, the two DXA

systems show T-score inconsistencies at both the spine (0.1 SD) and femoral neck (0.9 SD). While the observed discrepancy at the spine is of little clinical significance, the large difference at the femoral neck is of great clinical importance. Using the manfacturer-reported young normal standard deviation score, significant disagreements occur between DXA instruments when the WHO criteria are used at the femoral neck. However, using published data from other studies, this discrepancy can be eliminated by properly redefining the femoral neck young normal mean and standard deviation.

This study confirms the earlier report of Pocock et al. [7], who reported a significant discrepancy in the young normal percentage values at the femoral neck between Hologic and Lunar. We have extended this earlier investigation by looking at the standard deviation scores calculated by the two manufacturers, as well as suggesting ways of correcting the discrepancy. Several possible reasons exist for the inconsistent definition of the femoral neck young normal mean and standard deviation. For example, differing definitions of what constitutes a "normal" population may be partially responsible. Should a normal population be limited to healthy adults, or should it include a random sample of the population, independent of health status? In the latter case, individuals with existing disease, including osteoporosis, would be included. In practice, the precise definition of "normal" may not be as important as having a consistent definition across all types of densitometers. Sampling error may also play a role. The currently defined values for the female young normal mean and standard deviation for both DXA systems are based on measurements in a relatively small number of women in the young normal range. To expect a sample of several hundred or even thousand women to accurately represent the young normal BMD and standard deviation of the population as a whole may be unreasonable.

Besides differences in the reference populations, the statistical models used to describe the data also differ. Hologic uses cubic equations to define their reference curves. This forces a peak value to occur at the young normal age. In contrast, Lunar uses a tri-linear fit to the data, assuming BMD to be linear from age 20 to 45 years. Thus the Hologic young normal value can be expected to be relatively larger than the Lunar value, resulting in a larger observed prevalence for osteoporosis as was observed in this study. Simply using a consistent statistical model may eliminate a large proportion of the discrepancy in the young normal mean.

While adjusting the young normal mean and standard deviation did resolve the T-score discrepancy at the femoral neck, it does not address the question of what the "true" normative data are. It is important to note that the NHANES data used to provide the redefined young normal mean and standard deviation are taken from a sample of just under 200 non-Hispanic white women from the United States only. Different values can be expected for different countries and races. This study underscores the urgent need for the establishment of a large common normative database to be used by all DXA systems. Universal definition of osteoporosis based on a standard deviation score can only be applied if a consensus is established. Otherwise, misdiagnoses such as those seen in this study will occur depending on the densitometer used. Note that this may also necessitate a recalculation of the WHO criteria if the young normal values are redefined. The results of this study indicate a change in the definition of osteoporosis from 2.5 SD below young normal to approximately 2.0 SD at the femoral neck. However, this must be confirmed through the establishment of a universal normative database.

Until a consistent normative database is developed, it is possible to circumvent this normative discrepancy using the redefined young normal mean and standard deviation as proposed in this study. For research trials with a femoral neck BMD entry criterion, standardized BMD (sBMD, in mg/cm^2) can be used as opposed to standard deviation scores [6]. However, the question of what constitutes the true normal population remains.

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