

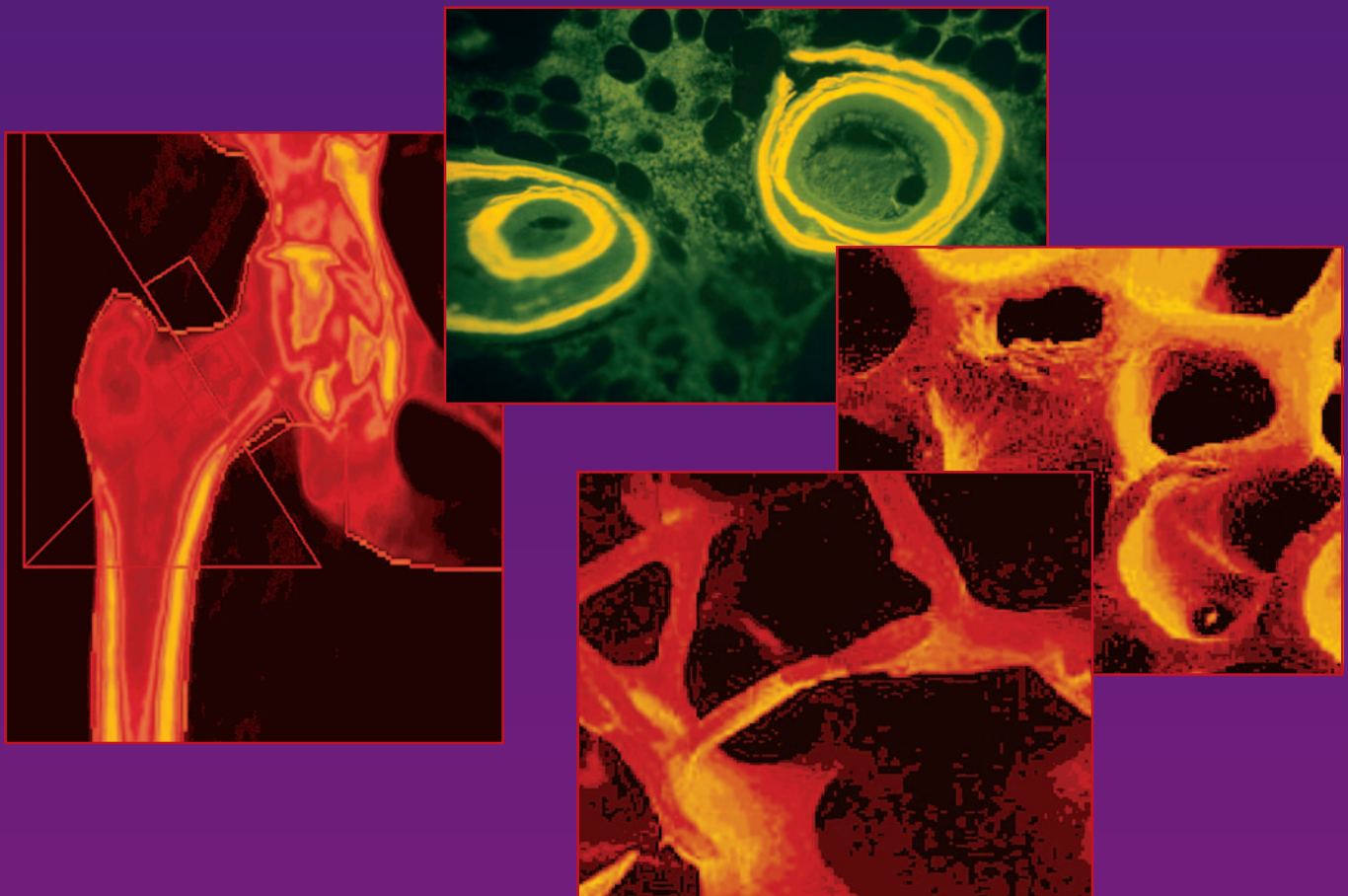
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## Original Article

# Dual X-Ray and Laser Absorptiometry of the Calcaneus

*Comparison With Quantitative Ultrasound and Dual-Energy X-Ray Absorptiometry*

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## Abstract

The aim of our study was to evaluate the reproducibility and the diagnostic accuracy of a new device for the assessment of bone mineral density (BMD) of the heel, called dual X-ray and laser (DXL Calscan). This technique associates X-ray absorptiometry to the measure of heel thickness with a laser beam. The calcaneus BMD, calcaneus quantitative sonography (QUS), and lumbar spine and total-body BMD, were evaluated in 40 postmenopausal women. On the basis of the BMD T-score measured by dual-energy X-ray absorptiometry (DXA) of L2–L4, 20 women were classified as osteoporotic and 20 women were considered nonosteoporotic according to the WHO classification. The short-term coefficient of variation of the DXL was 2.4% and 1.7% in osteoporotic and nonosteoporotic women, respectively. The calcaneus BMD was lower in osteoporotic than in nonosteoporotic women. Among osteoporotic patients, 14 patients had a T-score lower than –2.5 at Calscan, whereas only 4 patients classified as nonosteoporotic based on the lumbar spine BMD were misclassified by Calscan. In these patients, the sensitivity and specificity of heel ultrasound measurements were 70% and 85%, respectively. The DXL BMD was highly correlated with the total-body BMD, Stiffness at the calcaneus, and the L2–L4 BMD. In conclusion, the new measuring device the Calscan DXL appeared easy to use, the time of examination was relatively short, and the reproducibility was sufficiently good; the diagnostic accuracy and relationships with other devices were good.

**Key Words:** DXL; DXA; BMD; QUS; osteoporosis.

## Introduction

Dual-energy X-ray absorptiometry (DXA) of hip and spine sites is actually considered the “gold standard” for the noninvasive diagnosis of osteoporosis (1–5). Several large studies have confirmed that for each standard deviation decline in bone mineral density (BMD), there is an approximate dou-

bling of fracture risk (6–10). Since its introduction, many peripheral devices have been originated to complement the well-established DXA of axial skeleton because of the increasing demand for bone densitometric assessment. One of the widespread technique utilizes quantitative ultrasound (QUS) measurement of the calcaneus that is able to identify those individuals at risk of osteoporotic fractures (11,12). Indeed, a low BMD at a peripheral skeletal site could be used to predict fractures at the spine, hip, and nonvertebral sites (7,13,14). Recently, a new technique called the dual X-ray and laser (DXL Calscan) for the heel BMD evaluation has been proposed (15). It is a new absorptiometry technology based on a three-component model that complements a dual-wavelength X-ray source with laser definition of the object thickness; the

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coupling of the two methods allow us to more accurately exclude lean and fat tissue from the measurement area and to reduce error resulting from the inhomogeneous composition of soft tissue (16).

The aim of the study was, first, to analyze the short-term reproducibility and the diagnostic accuracy of the new available heel imaging device DXL Calscan and, second, to evaluate the relationships of the obtained BMD values with the DXA BMD of the lumbar spine, total-body BMD, and QUS of the calcaneus in a population of postmenopausal Italian women with or without osteoporosis.

## Materials and Methods

From a large number of patients referred to the Metabolic Disease Unit of the University of Siena for bone status evaluation, a cohort of 40 consecutive postmenopausal women (aged 48–72 yr) were enrolled in the study. Women with a history of amenorrhea, spinal arthritis changes, vertebral fractures, and any treatments or disease known to affect bone metabolism were excluded. All patients were informed about the nature of the study and consent was obtained from each participant.

Using the BMD-based WHO criteria (17), 20 subjects were categorized as being osteoporotic (BMD measured at the lumbar spine  $\geq 2.5$  standard deviations below the young female adult mean: T-score of  $-2.5$  or below) and 20 women as were categorized as nonosteoporotic (T-score above  $-2.5$ ). Among nonosteoporotic women, 10 were osteopenic (T-score  $> -2.5$  and  $< -1$ ) and 10 were normal (T-score  $> -1$ ). All subjects had QUS and DXL measurements of the calcaneus and total-body BMD assessment, in addition to a L2–L4 BMD scan.

The DXA measurements were performed using a Lunar DPX densitometer (Lunar Radiation Corp., Madison, WI). The features of the DPX unit were previously expressed (18). As ancillary results of total-body scan, the DPX device provides data on body composition and, particularly, fat and lean mass (in grams).

The QUS measurements were done by a calcaneus device, the Achilles Plus (Lunar Radiation Corp., Madison, WI). The Achilles measures the speed of sound (SOS), Broadband ultrasound attenuation (BUA) and a clinical index called Stiffness is calculated from the mean SOS and BUA measurements according to the formula  $\text{Stiffness} = [(0.67 \times \text{BUA}) + (0.28 \times \text{SOS})] - 4.20$ . The precision of this instrument has a coefficient of variation of 1.5% with regard to Stiffness (19,20). The T-score precision of the heel ultrasound has been reported to be about 0.2 (21,22).

The BMD of the calcaneus was measured by a new portable device, the DXL Calscan (Demetech, Solna, Sweden) that is able to calculate the BMD by a fully automatic location of the region of interest and to perform a scan very quickly ( $< 1$  min) with a radiation effective dose administration less than  $0.2 \mu\text{Sv}$  (15,23). The DXL measurements complement the DXA with the laser-based measurement of the thickness site.

To evaluate the short-term precision of DXL Calscan, each subject underwent three repeated measurements on the same day with repositioning between each scan. The precision error

Table 1  
Anthropometric and Densitometric Features  
of Women Entered in the Study (mean  $\pm$  SD)

Subjects	Osteoporotic (n = 20)	Nonosteoporotic (n = 20)
Age (yr)	65.7 $\pm$ 8	61.5 $\pm$ 9
Height (cm)	156 $\pm$ 7	157 $\pm$ 7
Weight (kg)	59 $\pm$ 9	69 $\pm$ 13*
BMI (kg/m <sup>2</sup> )	24.1 $\pm$ 3.4	27.9 $\pm$ 6.5*
Fat mass (kg)	21.5 $\pm$ 6.1	27.9 $\pm$ 9.0*
Lean mass (kg)	35.0 $\pm$ 3.9	38.1 $\pm$ 5.6
Heel BMD (g/cm <sup>2</sup> )	0.273 $\pm$ 0.05	0.397 $\pm$ 0.09*
Heel Stiffness (%)	60.84 $\pm$ 11.47	81.89 $\pm$ 16.31*
L2–L4 BMD (g/cm <sup>2</sup> )	0.794 $\pm$ 0.12	1.148 $\pm$ 0.17*
Total-body BMD (g/cm <sup>2</sup> )	0.926 $\pm$ 0.07	1.107 $\pm$ 0.12*

Note: Values are given as mean  $\pm$  SD. BMI = body mass index.  
\*  $p < 0.05$  by the unpaired *t*-test.

was calculated by dividing the root mean square (rms) of the standard deviation by the mean for all subjects and expressing the result as a percentage (coefficient of variation: CV%) (24,25). Standardized precision was also calculated according to the formula  $\text{T-score precision} = (\text{rms SD}/\text{young adult SD})$  (26). The young adult population SD (standard deviation) was  $0.06 \text{ g/cm}^2$ , as reported by Kullenberg and Falch (27).

The diagnostic accuracy of DXL Calscan and heel ultrasound was estimated calculating sensitivity (the fraction of patients with correctly identified disease) and specificity (the fraction of currently identified controls) at various cutoffs. Osteoporotic patients are defined by a DXA of the lumbar spine below a T-score of  $-2.5$ . Differences in bone mass values at different skeletal sites between the two groups were tested by the unpaired *t*-test. The relationships between the values obtained by different techniques were evaluated using Pearson's correlation coefficient, standard error of the estimate as an indicator of prediction accuracy, and *p*-values for testing significance of the correlations. All statistical analyses were done with SPSS (release 6.1; Chicago, IL, USA).

## Results

Table 1 sets out the anthropometric features of the women included in the study and the mean values  $\pm$  standard deviation of the measured variables. Women with osteoporosis were slightly older and significantly lighter than nonosteoporotic subjects, above all for a reduction of fat mass.

The heel BMD, heel stiffness, and total body BMD measurements were significantly lower in the osteoporotic women than in nonosteoporotic women (Table 1).

The short-term reproducibility of DXL, expressed as the coefficient of variation, was 2.4% and 1.7% in osteoporotic

Table 2  
Correlations Among DXL, DXA, QUS, Fat Mass, Lean Mass, and Age

	Total-body BMD	Lumbar spine BMD	Stiffness	Fat mass	Lean mass	Age
DXL (g/cm <sup>2</sup> )	$r = 0.88^*$ (0.05)	$r = 0.77^*$ (0.006)	$r = 0.86^*$ (0.005)	$r = 0.47^*$ (0.008)	$r = 0.42^*$ (0.008)	$r = -0.42^*$ (0.008)
Total-body BMD (g/cm <sup>2</sup> )	–	$r = 0.83^*$ (0.007)	$r = 0.83^*$ (0.007)	$r = 0.53^*$ (0.11)	$r = 0.43^*$ (0.12)	$r = -0.48^*$ (0.11)
Lumbar spine BMD (g/cm <sup>2</sup> )		–	$r = 0.68^*$ (0.17)	$r = 0.54^*$ (0.19)	$r = 0.53^*$ (0.19)	$r = -0.33^{**}$ (0.21)
Stiffness (%)			–	$r = 0.36^*$ (16)	$r = 0.27^{**}$ (17)	$r = -0.55^*$ (14)
Fat mass (kg)				–	$r = 0.66^*$ (6.2)	$r = -0.08$ (8.3)
Lean mass (kg)					–	$r = -0.13$ (5.0)

Note: The number in parentheses is the standard error of estimate.

\*  $p < 0.01$ ; \*\*  $p < 0.05$  as significance of Pearson's correlation coefficient; SEE, standard error of estimate.

and nonosteoporotic women, respectively. The short-term standardized precision for the heel BMD expressed in T-score units was 0.6 for three repeated measurements.

The relationships among DXA, QUS, DXL, age, fat mass, and lean mass were calculated for the pooled group and correlation coefficients, standard error of estimates, and  $p$ -values are reported in Table 2. All skeletal sites showed the expected negative correlation with age and the positive correlation with fat and lean mass.

The DXL Calscan was highly correlated with total-body BMD ( $r = 0.88$ ;  $p < 0.01$ ) and Stiffness of the calcaneus ( $r = 0.86$ ;  $p < 0.01$ ). Moreover, DXL also showed a significant correlation with the axial BMD measured at the lumbar spine ( $r = 0.77$ ;  $p < 0.01$ ).

Of those patients who were classified as osteoporotic on central DXA (T-score  $\leq -2.5$ ), 70% were similarly identified by DXL Calscan using the T-score provided by the manufacturer. With regard to patients classified as nonosteoporotic by central DXA (T-score  $> -2.5$ ), 80% were rightly identified. In these patients, the sensitivity and specificity of heel ultrasound measurements were 70% and 85%, respectively. In Table 3 are reported sensitivity and specificity of DXL Calscan and QUS at various cutoffs, osteoporosis being indicated on a central DXA T-score cutoff  $\leq -2.5$ .

## Discussion

It has been estimated that only 25% of Caucasian postmenopausal women in the United States have access to bone densitometry services (28), so the acceptance of QUS and other peripheral devices has given more people the opportunity to have an assessment of their skeletal status (29). Many studies have shown that BMD measurements at peripheral skeletal

Table 3  
Sensitivity and Specificity of DXL Calscan and QUS Devices at Various Cutoffs

	Cutoff (SD)	Sensitivity (%)	Specificity (%)
DXL	0	100	0
	-0.5	100	10
	-1	100	30
	-1.5	100	65
	-2	100	70
	-2.5	70	80
	-3	50	90
Stiffness	0	100	10
	-0.5	100	15
	-1	100	35
	-1.5	95	50
	-2	90	75
	-2.5	70	85
	-3	55	85

Note: Osteoporosis was indicated as a lumbar spine T-score  $\leq -2.5$ .

sites can be used to assess the risk of fracture at the spine, hip, and nonvertebral sites in older Caucasian women (14).

In this study, we tested a newly developed device based on a three-component model. Conventional DXA technology requires a two-component model for the human body, which provides bone mineral and soft tissue. However, soft tissue composition is not uniform because fat tissues have different attenuation coefficients with respect to water, muscle, or most

organs. Moreover, the fat tissue has an inhomogenous distribution in the body, such as in the axial skeleton and in yellow bone marrow and this allows an accuracy error as large as 20–30% with conventional DXA techniques (16).

Our preliminary data showed that DXL Calscan had a short-term reproducibility (1.7% in nonosteoporotic subjects and 2.4% in osteoporotic women) slightly worse than that reported in previous studies using both DXL Calscan (15) and DXA measurements of the heel (30–33). Also, T-score precision were higher compared to ultrasound measurements. However, our women were elderly and it is known that less bone mass gives a higher coefficient of variation (18). The precision of DXL Calscan was independent of the height, weight, and body mass index of patients.

The diagnostic accuracy of DXL Calscan and QUS using lumbar spine BMD as the reference site changed according to the various cutoffs. A T-score of  $-2.5$  or less identified less women as osteoporotic using the os calcis, but both DXL Calscan and QUS showed an acceptable level of diagnostic discrimination. However, the choice of the cutoff depends on the number of false-positive and false-negative cases judged acceptable on clinical practice (34). Our data confirm that the threshold T-score for peripheral assessment of BMD is greater than that used in axial measurements (29,30,35–37). Using a T-score of  $-2.0$  for DXL Calscan while keeping the cutoff for central DXA constant at  $-2.5$ , we obtained a full concordance regarding the identification of osteoporotic women with an high specificity. Thus, a value of the T-score set at  $-2.0$  can be utilized in the diagnosis of osteoporosis by DXL. Also, QUS showed a good concordance, as shown in Table 3. In agreement with Hans et al. (38), we found a Stiffness T-score of  $-1.5$  at 95% sensitivity and a T-score of  $-2.5$  at 85% specificity.

Other studies comparing the central vs peripheral DXA assessment of the BMD found similar values of specificity for os calcis measurements was poorer (30,39,40). These discrepancies could be explained by the differences in recruitment, number of subjects, and use of different QUS and DXA devices (41). However, our results indicate that DXL Calscan is able to identify osteoporotic subjects with an acceptable level of specificity.

As expected, the correlation between heel BMD and QUS was highly significant. On the other hand, the relationship between DXL and total-body BMD or L2–L4 BMD was greater than that reported between DXA measurements of the calcaneus and other skeletal sites (30,34,42–44). Considering the difference in the composition of cortical and trabecular bones between the heel and total body, we expected a weaker correlation; indeed, an  $r$ -value of about 0.7 has been reported regarding the relationship between Stiffness and total-body BMD (45). In addition, our data showed a weak relationship between Stiffness and lumbar spine BMD as compared to DXL, although the  $r$ -value was highly significant ( $r = 0.68$ ;  $p < 0.01$ ). However, despite the high  $r$ -value, the standard error of estimate (SEE), an expression of predictive accuracy, was too large, casting suspicion on the predictive value,

especially when DXL Calscan measurements were compared to those of the lumbar spine ( $SEE = 0.06 \text{ g/cm}^2$ ). Also, Stiffness showed a high SEE both for total-body and lumbar spine BMD (Table 2). Therefore, it is not possible to predict the BMD of L2–L4 by measuring heel BMD or heel Stiffness (46,47).

Our study has several limitations. The number of subjects is relatively low and a large number probably would present more reliable results. Women included in the study were elderly, and in the nonosteoporotic group, there were several osteopenic patients, which could be the cause of the relatively large error of precision of DXL Calscan. We used only the lumbar spine BMD without assessment of the proximal femur, which is considered the “gold standard” for diagnosing osteoporosis (48). Moreover, we utilized the manufacturer’s data to calculate the T-score. A portion of the discordance in diagnostic accuracy can be alleviated by the development of own reference database and by measuring the femur BMD (49–51).

In conclusion, in the present study, reproducibility, intersite correlations, and discriminatory ability of DXL Calscan of the calcaneus were assessed in osteoporotic and nonosteoporotic women. Our data showed that DXL Calscan provides a convenient method of measuring skeletal BMD with some advantages over axial BMD; indeed, it is easy to use and transportable and it perform fast scanning with a minimal dose of radiation.

However, these data need further investigation to establish whether DXL represents a real improvement compared to heel ultrasound and to define the optimal use for different patient groups.

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