Ultrasound measurements of the os calcis

Side differences and prediction of bone density in 39 persons

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We measured the ultrasound Stiffness Index (SI) of the os calcis bilaterally with the Achilles Ultrasound Bone Densitometer in 30 women and 9 men, aged 53 (31–76) years. Lumbar spine BMD (percent of mean per age group) was measured with a DXA bone densitometer. Supplementary BMD measurements of the hip and the nondominant radius were made in 29 of the 39 persons; 11 of them had had a unilateral total hip arthroplasty (THA), the rest were healthy control subjects.

SI values were in the range of 78–138 percent. Large individual differences between the right and the left os calcis were seen, even in healthy controls (CV 6.3 percent), although no differences between the means of the two sides were found. The prediction of SI of one os calcis from that of the other was inaccurate (SEE 6 percent). The SI of the dominant os calcis correlated significantly to the lumbar spine BMD, to the hip BMD and to the non-dominant radius BMD. In the group with unilateral THA the individual SI side-differences were larger (CV 8 percent; SEE 9 percent), but no systematic difference between the means of the operated and non-operated sides was found. We conclude that there are large random individual differences between the SI of the right and the left os calcis and recommend measurement of both sides for classification of one individual.

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The two commonly used ultrasound bone variables for osteoporosis screening are Speed Of Sound (SOS) and Broadband Ultrasound Attenuation (BUA); both SOS and BUA correlate with Bone Mineral Density (BMD) in the heel and BMD at other sites (Glüer et al. 1992, Kaufman and Einhorn 1993). With the LUNAR Achilles Ultrasound Bone Densitometer, the Stiffness Index (SI), an index combining SOS and BUA, has been shown to correlate slightly better to BMD than SOS and BUA alone, and to distinguish better between normals and osteoporotics than when using BUA alone (Lees and Stevenson 1993). Which side is it best to measure? No recommendations are given. Published data on side variability are scarce, and it is not generally accepted that this method can be used to screen for low bone density (Faulkner et al. 1994).

We studied the difference between the right and left os calcis and assessed the correlation of the os calcis SI versus the BMD of the lumbar spine, the hip and the non-dominant radius.

Patients and methods

Ultrasound bone densitometry

The SI of the os calcis was measured bilaterally with the LUNAR Achilles Ultrasound Bone Densitometer in 30 women and 9 men, aged 53 (31–76) years. 4 women and 7 men of the same mean age were operated on with a unilateral total hip arthroplasty (THA) 4.5–6 years before the measurements. The rest were healthy controls. All had normal feet.

With the LUNAR Achilles ultrasound bone densitometer (LUNAR Corporation, Madison, WI 53713, U.S.A.), the foot is placed in a 37 °C water bath with surfactant, after both sides of the heel have been scrubbed with an alcohol swab (attenuating materials and air pearls on the skin interfere with precision). The patient's calf rests comfortably and the foot is held in position by a toe peg. The skin temperature must be stabilized before scannings are done; several measurements are made by two unfocused transducers: one transmitter and one receiver. When the scan data stabilize, the data collection stops and the results appear on a screen. The procedure lasts 3–5 minutes per foot.

BUA is measured in dB/MHz, SOS in m/s; the SI, an empirical clinical index of bone quality combining BUA and SOS, is expressed as a percentage, i.e., the SI in terms of "percent age" is the observed SI value compared to the expected SI value of a reference group of the same age and sex.

Table 1 A. Os calcis stiffness index (percent age): mean values (SD), differences between sides, SD of individual differences, and coefficients of variation (CV).

Group	No prosth. n 28	Hip prosth. n 11
Dominant side	106 (14)	110 (13)
Nondominant side	107 (15)	112 (9)
Difference	–0.4 ns	–1.4 ns
SD of individual diff.	6.7 ns	9.2 ns
CV (percent)	6.3	8.3
Right side	106 (14)	110 (13)
Left side	107 (15)	112 (9)
Difference	–0.4 ns	–1.4 ns
SD of individual diff.	6.7 ns	8.8 ns
CV (percent)	6.3	7.9
Hip prosth. side		110 (13)
No prosth. side		112 (9)
Difference		–1.6 ns
SD of individual diff.		9.2 ns
CV (percent)		8.3

ns not significant (paired Student's *t*-test),
CV SD/mean value of the two sides.
Note: Large biological variation (SD) and large SD of individual differences, but identical mean values.

Table 1 B. Os calcis stiffness index (percent age). Comparison of the two sides. Linear regression analysis (r), 95 % confidence interval (CI) of r, and standard error of Y estimate (SEE; percent)

Sides compared	r	CI of r	SEE
No prosth., n 28			
Right vs. left	0.90 ***	(0.79–0.95)	6.3
Dominant vs. nondominant	0.90 ***	(0.79–0.95)	6.3
Hip prosth., n 11			
Right vs. left	0.71 *	(0.19–0.92)	9.3
Dominant vs. nondominant	0.70 *	(0.17–0.92)	9.7
Hip prosth. vs. no prosth.	0.71 *	(0.19–0.92)	9.7

* $p < 0.05$, *** $p < 0.001$.

Dual energy X-ray Absorptiometry (DXA)

The lumbar spine BMD was measured with the HOLOGIC QDR-2000 DXA Bone Densitometer (HOLOGIC Inc., Waltham, MA 02154, U.S.A.) in all subjects.

Supplementary BMD measurements of the hip and the non-dominant radius were made in the patients with a unilateral THA and in 18 controls.

Two scan modes were available: a fan beam mode using 32 detectors simultaneously and a single beam mode with one detector. Measuring time was 2–10 min, the fan beam mode being the faster one. Single beam mode was used in all our measurements because of problems of accuracy and precision with the fan beam mode (Eiken et al. 1994).

The results are given in g/cm^2 (BMD being a projected areal density) and g (BMC being integrated Bone Mineral Content); percentages are presented as with the LUNAR Achilles ultrasound bone densitometer.

For statistical calculations, the Student's t-test and correlation analysis were used. $P < 0.05$ was considered significant.

The study was approved by the local Ethics Committee.

Results

The means of the SI of the right and left os calcis were not significantly different. Large, insignificant, individual random differences between the right and left os calcis were found, the coefficient of variation (CV) being 6.3 percent in normals and about 8 percent in persons with unilateral THA (Table 1A). No systematic difference between the means of the operated and non-operated sides was found.

The SI of the right and left os calcis correlated well. However, prediction of SI of one os calcis from the SI of the other was not possible, SEE being 6.3 percent in healthy people and about 9.5 percent in patients with THA (Table 1B) (the measured SI range was 78–138 percent age) (Figure 1).

In healthy subjects, the SI of the dominant os calcis was significantly—although not very well—correlated to the lumbar spine BMD (Table 2), to the hip BMD, and to the non-dominant radius BMD (Table 3). Correlations between SI of the non-dominant os calcis or the mean SI of both sides and BMD measurements were generally weaker, especially for the hip and the lumbar spine (Tables 2 and 3), but no significant differences between the correlations were found (large 95 percent confidence intervals).

The SI of the os calcis was not significantly correlated to the hip BMD and radius BMD in persons with THA.

One person (a healthy man, 60 years old) had repeated measurements within 1 week: SI (percent age) was 118 and 116 on the right side, 102 and 100 on the left side, i.e., the short-time precision error for this patient was less than 2 percent.

Discussion

The os calcis contains about 98 percent trabecular bone. Previous studies have suggested that the SOS reflects bone density and elasticity (Greenfield et al. 1981, Kann et al. 1994) and the BUA reflects density

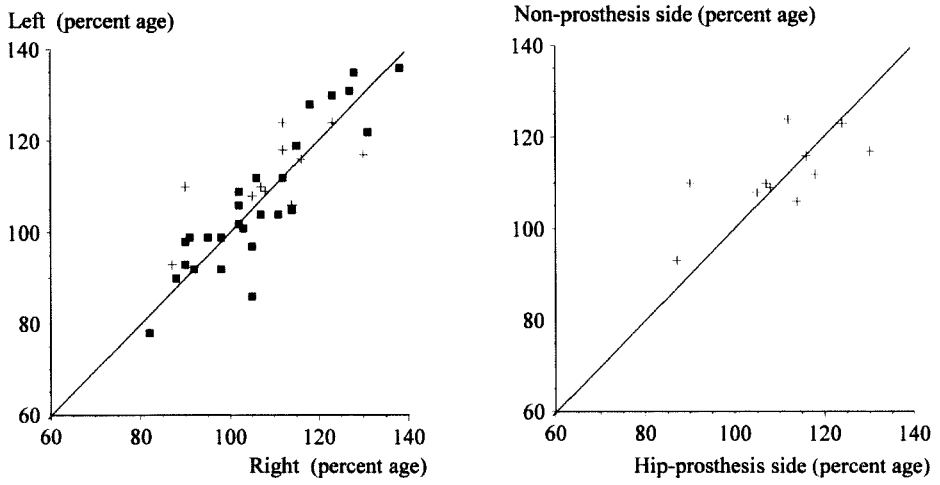

Figure 1. Os calcaneus stifness index (percent age): Right side versus left side (left) and prosthesis side versus no prosthesis side (right). Line of identity is drawn. ■ healthy subjects; + subjects with unilateral THA.

and structure (Glüer et al. 1993). Generally, ultrasound waves move faster through denser materials (SOS) and the interaction of the waves with the medium in which they propagate (e.g., the bone trabeculae) results in a loss of energy (BUA).

SOS and BUA have been combined into the stiffness index (SI) in the LUNAR Achilles scanner. Lees and Stevenson (1993) found that SI correlated slightly better to BMD of other sites than did the SOS and BUA alone, and that SI distinguished better between normals and osteoporotics than did BUA alone; SI has no relation to the biomechanical terms used in physics text books, but is rather an empirical, clinical index of bone quality.

Table 2. Lumbar spine BMD (percent age) versus os calcis stiffness index (percent age). Linear regression analysis (r), 95 % confidence interval (CI) of r, and standard error of Y estimate (SEE; percentage)

BMD versus	r	CI of r	SEE
No prosth., n 26			
Dominant side	0.51 **	(0.15–0.75)	13
Mean [a]	0.47 *	(0.10–0.72)	13
Nondomin. side	0.40 *	(0.02–0.68)	14
Right side	0.51 *	(0.15–0.75)	13
Left side	0.40 *	(0.02–0.68)	14
No prosth., n 18			
Dominant side	0.55 *	(0.11–0.81)	12
Mean [a]	0.46 ns	(–0.01–0.76)	13
Nondomin. side	0.36 ns	(–0.13–0.71)	15
Hip prosth., n 11			
Dominant side	0.51 ns	(–0.13–0.85)	12
Nondomin. side	0.11 ns	(–0.52–0.67)	9
Right side	0.50 ns	(–0.14–0.85)	12
Left side	0.14 ns	(–0.50–0.68)	9
Hip prosth. side	0.22 ns	(–0.44–0.72)	12
No prosth. side	0.10 ns	(–0.53–0.66)	9

No prosth. (n 18) are subjects who also had measurements at the hip and at the non-dominant radius.
[a] Mean = (right side + left side) / 2,
* $p < 0.05$, ** $p < 0.01$, ns not significant.

The in vivo precision error with the Achilles scanner is 0.3 percent for SOS, 1.5 percent for BUA, and 1.9 percent for the combined SI. Only 2 published studies have measured the short-time precision of SI in more than 20 subjects: CV was 1.9 percent in both studies (Mazess et al. 1992, Hans et al. 1994) (Table 4). BMD measurements made with DXA have precision errors between 1 and 2 percent (Genant et al. 1991). One of the main problems encountered in the ultrasound assessment of the os calcis is the heterogeneity of the bone; especially BUA is affected by small changes in trabecular orientation (e.g., due to minor changes in heel positioning) (Glüer et al. 1993). The high precision of SOS does not imply better ability to distinguish between osteoporotic and normal subjects because of a relatively narrower range of bone ultrasound velocities than the range for BUA (Lees and Stevenson 1993, Schott et al. 1993). When the effective range is taken into account, SI has good precision (Lees and Stevenson 1993). An increase in heel width and fat thickness provides an underestimate of SOS, but has no significant effect on BUA (Kotzki et al. 1994).

It is a common mistake among manufacturers of medical equipment to introduce new technology prematurely. One of the commonest errors is misuse of correlation and regression analyses. This paper gives an example of good correlation and almost identical

Table 3. Hip BMD and non-dominant radius BMD versus lumbar spine BMD and os calcis stiffness index (percent age values). r values of linear regression analysis. n 18 (without hip prosthesis)

	Hip				Non-dominant radius		
	Neck	Troch	Total	Ward	1/3	Mid	UD
versus [a]							
spine	0.73***	0.65**	0.62**	0.67**	0.49*	0.47*	0.54*
os calcis DS	0.72***	0.83***	0.79***	0.64**	0.59**	0.61**	0.52*
os calcis mean	0.62**	0.72***	0.68**	0.51*	0.62**	0.61**	0.50*
os calcis NDS	0.50*	0.58*	0.53*	0.37 ns	0.62**	0.58*	0.46 ns

[a] DS dominant side, mean (right side+left side) /2, NDS non-dominant side.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Note: The 95 percent confidence intervals are so large for all the r-values that no r-values differ significantly!

Table 4. Short-time in vivo precision. Coefficient of variation (CV) (percent)

Reference	SOS	BUA	SI	n	Comments
Faulkner et al. (1994)	0.5	1.8	2.14	1	26 times over a 4-week period
Hans et al. (1994)	0.23	1.83	1.9	95	2–3 times each, (5 centers, 15–25 persons/center)
Lees and Stevenson (1993)	0.19	1.38	1.49	5 (normals)	5 times within 5 days
	0.13	1.09	1.46	5 (osteoporotics)	5 times within 5 days
Mazess et al. (1992)	0.3	1.9	1.9	22	14 measurements/case over several weeks
Schott et al. (1993)	0.15	0.93	–	20 (normals)	3 times

means of SI in the two measuring sites, combined with individual random differences that are so large that in one individual it is clearly impossible to predict SI of one calcaneus from that of the other. Regression analysis also showed that our predictions of bone density on various skeletal sites from SI in our hands are so poor that SI of the os calcis cannot predict or replace BMD at other sites.

It might not be surprising that patients with walking problems have large individual differences between sides. On the other hand, it is striking that healthy controls have large individual side-differences as well (CV 6.3 percent, or 3.3 times the precision error). The measurements on the right and the left heels correlated reasonably well (r 0.90, f 26, $p < 0.001$), but this does not justify the use of only one of the two sides in a given subject when the problem concerns classification or diagnosis in this subject.

Correlations between the dominant os calcis and BMD of the hip and the non-dominant forearm were high in controls but the correlation to the lumbar spine BMD was weak (Tables 2 and 3). These findings are in accordance with those of previous studies (Glüer et al. 1992, Kaufman and Einhorn 1993, Salamone et al. 1994). SI of the dominant os calcis was systematically, but not significantly, better correlated to the BMD measurements than the SI of the nondominant os calcis and the mean of both sides.

Only two published reports include comparisons between the two sides (Poll et al. 1986, Herd et al. 1992). Poll et al. found relatively large but not significant differences between BUA of the right and the left os calcis and suggested that both heels should always be measured and the mean value be used. Herd et al. (1992) observed a slightly higher, but still insignificant BUA result for the left heel. Our study showed the same systematic tendency for SI.

The explanation of the side-differences of SI is not obvious. One explanation could be the fact that no normalization for bone size was done. Further, SI is likely to reflect differences in the load on the legs and inborn anatomical differences between sides.

We recommend that both sides should be measured until better procedures have been developed, and that ultrasound bone measurements should be evaluated with caution.

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