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Quantitative ultrasound measurements of the calcaneus in the prediction of lumbar spine degeneration

Received: 24 June 2003
Revised: 4 October 2003
Accepted: 17 October 2003
Published online: 10 February 2004
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Abstract A cross-sectional study was conducted to evaluate the possible use of a low-cost radiation-free technique in the prediction of degenerative changes in the lumbar spine. Although an inverse correlation between osteoporosis and degenerative changes in the lumbar spine has been reported, no previous studies have asked whether there is a correlation between calcaneal quantitative ultrasound results and degenerative findings in the lumbar spine. In 117 patients with low back pain or pain in the lower limb, ultrasonographic parameters (speed of sound, broadband ultrasound attenuation, stiffness) of the calcaneus were correlated with evidence of degenerative changes and stenosis on magnetic resonance scans of the lumbar spine. Linear and logistic regression, as well as receiver operator characteristic curve analyses, were used to evaluate the correlation. Lumbar spine stenosis was associated with elevated calcaneal ultrasonographic parameters, particularly speed of sound. For the identification of a narrowing of the

lumbar spinal canal below 100 mm² of dural sac cross-sectional area, speed of sound showed 89% sensitivity and 75% specificity in males older than 60 years. In male patients, we also found a significant positive correlation between ultrasonographic parameters and scores on a degenerative scale that primarily reflects intervertebral disc degeneration ($P=0.019$ for speed of sound; $P=0.039$ for stiffness). In conclusion, calcaneal quantitative ultrasound is frequently used in elderly patients with low back pain as a diagnostic test for osteoporosis. The incidental finding of high values on ultrasonographic parameters in these subjects, particularly in males, is highly correlated with lumbar spine degeneration and stenosis, and can help to identify those symptomatic patients needing more extensive diagnostic testing.

Keywords Quantitative ultrasound · Calcaneus · Magnetic resonance imaging · Lumbar spinal stenosis · Lumbar degeneration

Introduction

The poor correlation between symptoms and findings of lumbar spine degeneration on imaging tests leads to both overuse and inappropriate use of diagnostic resources, and thus to increased costs and an elevated risk of complications [3, 9]. Expensive and time-consuming examinations

of the lumbar spine using magnetic resonance imaging (MRI) should be regarded only as diagnostic tools for chronically disabled subjects, or for the preoperative evaluation of patients in pain [3, 9]. It therefore would be useful to find a quick and low-cost technique for assessing the status of the lumbar spine in symptomatic subjects, to identify those who require more exhaustive diagnostic evaluation.

Several studies have shown a direct relationship between degenerative changes in the lumbar spine and bone mineral density (BMD) [15, 16]. Quantitative ultrasound (QUS) of the calcaneus is an inexpensive radiation-free technique whose results are directly correlated with BMD, as measured by dual energy X-ray absorptiometry at different sites [6, 13, 22, 31, 33].

The goal of this cross-sectional study was to examine the relationship between calcaneal QUS results and degeneration in the lumbar spine on imaging tests, in subjects with either low back pain (LBP) or pain in the lower limb, and to ascertain the possible clinical relevance of such an association.

Materials and methods

We studied 117 subjects who were hospitalised or attending an out-patient clinic for LBP, either radiating down the leg or not. Sixty-five subjects were women and 52 were men. The exclusion criteria were: (1) age less than 40 years (2) secondary causes of LBP, such as infections, tumours, or congenital anomalies of the lumbar spine (3) any use of corticosteroids for more than 1 month (4) therapy with anti-osteoporosis drugs for more than 3 months (5) malignancy (6) previous back surgery or (7) previous endocrine surgery.

After informed consent was obtained, we interviewed the patients to obtain personal and medical histories. The severity of pain was rated via patients' self-reported evaluations, using a six-point numerical rating scale anchored at one end by "no pain" and at the other by "worst pain imaginable". Patients were also asked about the chronicity of their symptoms, recalling the duration of their pain. Finally, they completed an Oswestry low back pain disability questionnaire [11], a reliable ten-item tool to assess disability resulting from LBP. The weights and heights of the subjects were also recorded.

Subsequently, we performed ultrasound assessments of the calcaneus using a Lunar Achilles ultrasound unit (Lunar, Madison, WI, USA). We obtained three measurements for each subject: speed of sound (SOS), broadband ultrasound attenuation (BUA), and stiffness of the calcaneus. SOS and BUA are ultrasonographic parameters with different clinical and physical meanings. Since sound waves pass more quickly through stiff objects than through more flexible objects, an increase in SOS means larger amounts of bone in the calcaneus.

BUA is an index of the attenuation of sound waves through the calcaneus that reflects characteristics of the bone different from the density, such as trabecular geometry and width of the calcaneus. The stiffness is a clinical index obtained from the combined data of SOS and BUA for evaluating bone quality. It is calculated automatically according to the formula: $\text{stiffness} = (0.67 \times \text{BUA} + 0.28 \times \text{SOS}) - 420$. Test-retest reliability was tested using a subset of 20 participants (10 women and 10 men) measured twice on two separate days. The coefficient of variation was 0.45, 2.4, and 2.1% for SOS, BUA, and stiffness, respectively. The mean scan time (mean $\pm$ SD) for QUS was 8.12 $\pm$ 2.6 min.

Anteroposterior and lateral radiographic views and MRIs of the lumbar spine were obtained from all subjects. The MRI scans were performed with a GE Vectra scanner (Milwaukee, WI, USA). T1- (Spin echo, TR 550, TE 25) and T2-weighted (Gradient echo, TR 700, TE 30) sagittal sections and T2-weighted transverse images (Gradient echo, TR 650, TE 30, 4 mm slice thickness) were obtained at 0.5 tesla. The mean scan time (mean $\pm$ SD) for MRI was 29 $\pm$ 4 min.

Scans performed at each intervertebral space from L2/L3 to L5/S1 were selected. These images were digitised and the dural sac

cross-sectional area at the most stenotic level was calculated. All measurements were performed in duplicate by two different operators who were specifically trained for the study, but who were unaware of the clinical pictures of the patients. Furthermore, two experienced neuroradiologists calculated the degree of degeneration in the lumbar spine on MRI scans, using a summative degenerative scale (SDS) [17]. They also were unaware of the clinical pictures and QUS findings of the patients.

On the SDS, points were assigned to the following: disc degeneration (0 = normal disc; 1 = degenerated disc), height of degenerated discs (0 = height of more than 10 mm; 1 = height of 5–9 mm; 2 = height of 4 mm or less), facet arthritis (one point for each arthritic joint), disc herniation (0 = no; 1 = yes), and degenerative spondylolisthesis (one point for each millimetre of vertebral slippage). Intervertebral disc intensity lower than that of the adjacent cerebrospinal fluid, and/or bulging discs on T2-weighted images, were considered to be positive evidence of degeneration. An intervertebral disc was considered to be herniated when it protruded or was extruded, following Jensen et al. [19]. Both dural sac cross-sectional area measurement and SDS calculation were repeated after 20 days. No significant variations were found in consecutive measurements on the same scan or between different operators.

Statistical analysis

The two sample t-test and chi-square test were used when appropriate. Univariate and multiple linear regression analyses were performed to discover variables that were significantly correlated with the following outcomes of interest: SDS score, degree of disability according to the Oswestry score, SOS, BUA, and stiffness of the calcaneus. All these outcomes were treated as continuous variables. The effect of the explanatory variables on the dural sac cross-sectional area was examined by univariate and multiple logistic regression analyses, using a dichotomous dependent variable based on the presence of stenosis of the spinal canal (0 = absent; 1 = present). For this purpose, a level was considered stenotic if the dural sac cross-sectional area was less than 100 mm² at the narrowest level [4, 14, 30].

The explanatory variables included in the multivariate analysis were: age (continuous), gender (categorical: 0 = female; 1 = male), body mass index (BMI) (continuous), SOS (continuous), BUA (continuous), stiffness (continuous), spinal stenosis (categorical: 0 = absent; 1 = present), pain intensity (continuous), pain duration (continuous), Oswestry score (continuous), SDS score (continuous), workload (categorical: 0 = sedentary; 1 = heavy), and comorbidities involving all organ systems and having required previous hospitalisation or any specific medications (categorical: 0 = none; 1=1; 2= $\geq$ 2).

All univariate analyses were adjusted for age and sex. In the women, the effect of the number of pregnancies (continuous), menopause (categorical: 0 = no, 1 = yes), and years since menopause (continuous) was also checked. For the multivariate analysis, possible relationships were firstly analysed for the group as a whole, and then for three subsets of subjects: over 60 years of age, women, and men. For the outcome variables SDS and Oswestry scores, different models were constructed with SOS, BUA, and stiffness as explanatory variables to avoid confounding. The effect of clinically relevant explanatory variables on the outcomes of interest was first evaluated with univariate analysis, and then was checked with multiple regression analysis models.

To evaluate the association of QUS parameters with spinal stenosis, receiver operator characteristic (ROC) curves were used. This method has already been used to assess the performance of different QUS parameters and BMD in the prediction of osteoporosis [25] and related risk of vertebral fracture [6]. ROC curves can be obtained by plotting sensitivity against 1-specificity for each value of a diagnostic test. The method is used to describe the accuracy of a test over a range of cut-off points. The results of tests that dis-

Table 1 Characteristics of the study group

	All subjects (117)		Men (52)		Women (65)	
	<i>n</i>	(%)	<i>n</i>	(%)	<i>n</i>	(%)
Age, year (mean±SD)	60.1±10.5		61.1±9.9		59.4±11	
Age, decade distribution						
40–50	23	19.6	7	13.5	16	24.6
51–60	34	29.0	16	30.7	18	27.7
61–70	38	32.5	21	40.4	17	26.1
>70	22	18.8	8	15.4	14	21.5
BMI (kg/m ²) (mean±SD)	28.1±4.4		26.3±3.4		29.5±4.6	
Oswestry score (mean±SD)	43.9±24.4		34.9±23.9		51.1±22.5	
LBP intensity	3.3±1.8		3.1±1.9		3.5±1.6	
LBP duration (months)	92±101		99.3±103.2		86.4±99.7	
Summative degenerative scale score (mean±SD)	8.6±4.6		7.2±3.3		9.8±5.2	
Dural sac cross-sectional area at the most stenotic level (mean±SD)	96.4±44.2		99.8±48.1		93.7±40.9	
Presence of spinal stenosis						
Yes	64	54.7	29	55.8	35	53.8
No	53	45.3	23	44.2	30	46.2
SOS (m/s) (mean±SD)	1528±34		1543±34		1516±29	
BUA (dB/MHz) (mean±SD)	121.3±15.7		129.2±12.6		114.9±15	
Stiffness (%) (mean±SD)	88.7±18.6		98.3±16.7		81±16.3	
Menopause						
Yes	–		–		43	66.2
No	–		–		22	33.8
Years since menopause	–		–		18.3±10.4	
Women with previous pregnancies						
Yes	–		–		61	93.8
No	–		–		4	6.2
Pregnancies (mean±SD)	–		–		3.2±1.9	
Workload						
Sedentary work	50	42.7	13	25	37	56.9
Manual work	67	57.3	39	75	28	43.1
Comorbidity						
0	84	71.8	35	67.3	49	75.4
1	24	20.5	12	23.1	12	18.5
≥2	9	7.7	5	9.6	4	6.2

criminate well crowd toward the upper left corner of the ROC curve; as the sensitivity is progressively lowered (the cut-off point is lowered), there is little or no loss in specificity in these tests until high levels of sensitivity are achieved. Tests that perform less well have curves that fall closer to the diagonal line running from lower left to upper right (describing a test that contributes no information at all). When the effectiveness in diagnosing the same clinical condition is tested by comparing different diagnostic methods, the wider the area under the ROC curve, the better the method. When a single parameter is tested, the best compromise between sensitivity and specificity is the best cut-off value for that parameter. Indeed, high sensitivity indicates a high capability of revealing a clinical condition, whereas high specificity indicates a high capability of excluding the same condition.

In the present study, the area under the ROC curve, sensitivity, specificity of each value of SOS, BUA, and stiffness in the diagno-

sis of lumbar spinal stenosis were evaluated. The best cut-off value for each ultrasonographic variable that was significantly related to spinal stenosis was identified in the study group as a whole and then in subjects over 60 years of age, men, and men over 60 years of age. A *P*-value less than 0.05 was considered significant. SPSS software (version 9) was used for data collection and statistical analysis.

Results

The characteristics of the 117 study participants are shown in Table 1. The only characteristics that significantly differentiated males and females were BMI, Oswestry score,

Table 2 Age- and sex-adjusted univariate analysis

Variable	SOS		BUA		Stiffness		Oswestry score		SDS Score	
	c	P	c	P	c	P	c	P	c	P
Age	-0.66	0.018	-0.38	0.002	-0.46	0.001	6.17 ⁻⁰²	0.769	0.11	0.005
Pregnancies ^a	-4.42	0.026	-1.53	0.127	-2.56	0.015	6.56 ⁻⁰²	0.968	0.79	0.028
Oswestry score	0.11	0.375	8.57 ⁻⁰²	0.121	7.83 ⁻⁰²	0.230	—	—	8.03 ⁻⁰²	0.653
SDS score	0.92	0.165	0.40	0.175	0.43	0.212	0.23	0.653	—	—
Spinal stenosis	16.21	0.005	4.29	0.096	7.43	0.014	-4.36	0.332	2.43	0.003

^aWomen selected**Table 3** Models of multivariate regression analysis

Variable		Model 1: SOS outcome		Model 2: BUA outcome		Model 3: stiffness outcome	
		Coefficient	P	Coefficient	P	Coefficient	P
All subjects (n=117)	Age	-0.80	0.006	-0.39	0.003	-0.49	0.001
	Sex	41.49	<0.001	21.73	<0.001	25.51	<0.001
	Oswestry disability score	9.92 ⁻⁰²	0.424	9.56 ⁻⁰²	0.083	8.73 ⁻⁰²	0.176
	SDS score	0.21	0.762	0.26	0.403	0.15	0.666
	Spinal stenosis	17.81	0.004	4.39	0.107	8.22	0.011
Women (n=65)	Age	-0.70	0.163	-0.24	0.319	-0.39	0.120
	Oswestry disability score	0.26	0.106	0.17	0.034	0.18	0.022
	SDS score	0.40	0.617	0.62	0.119	0.45	0.263
	Spinal stenosis	8.11	0.297	-0.82	0.829	2.76	0.473
	Workload	-7.99	0.287	-8.63	0.021	-9.27	0.015
Men (n=52)	Number of pregnancies	-4.55	0.031	-1.93	0.060	-2.65	0.012
	Age	-0.69	0.138	-0.24	0.197	-0.37	0.125
	Oswestry disability score	2.25 ⁻⁰²	0.904	7.51 ⁻⁰²	0.328	4.46 ⁻⁰²	0.644
	SDS score	2.95	0.030	0.80	0.142	1.35	0.053
	Spinal stenosis	25.10	0.007	8.13	0.030	11.89	0.013

SDS score, SOS, BUA, stiffness, and workload ($P \leq 0.002$ for all variables).

Results of the univariate analysis are reported in Table 2. Age was a negative predictor of SOS, BUA, and stiffness, and a positive predictor of SDS score. No correlation was found between the Oswestry score and degree of lumbar spine degeneration or spinal stenosis, and no clinically relevant correlation between any other explanatory variable and the outcomes was noted on univariate analysis. In the univariate logistic regression analysis, a condition of spinal stenosis was positively predicted by age [odds ratio (OR)=1.05; 95% confidence interval (CI)=1.01–1.09; $P=0.011$], BMI (OR=1.12; 95% CI=1.01–1.24; $P=0.029$), SOS (OR=1.02; 95% CI=1.01–1.03; $P=0.007$), stiffness (OR=1.03; 95% CI=1.01–1.06; $P=0.016$), SDS score (OR=1.19; 95% CI=1.06–1.34; $P=0.003$), and duration of LBP (OR=1.004; 95% CI=1.0003–1.009; $P=0.038$). No relationship was found with BUA.

Linear regression models with the ultrasonographic parameters as outcome variables are reported in Table 3.

Model 1 illustrates the relationship between the relevant explanatory variables and SOS. In the study group as a whole, multivariate analysis showed a significant decrease in SOS with increasing age, while the presence of spinal stenosis was associated with higher SOS values. In the subjects older than 60 years, the spinal stenosis retained its role of strong positive predictor of SOS ($P=0.004$). This was also true for men, for whom a positive association was also noted between the SOS and SDS score. In the women, no correlation of any explanatory variable with SOS was noted, except for a negative effect of parity. Determinants of BUA are reported in model 2. This outcome also decreased with increasing age. In men, spinal stenosis was the only positive predictor of BUA.

Model 3 reports variables that were significantly correlated with calcaneal stiffness. Age was negatively associated with this QUS parameter, whereas spinal stenosis was a positive outcome predictor. The same significant relationships were found in the group of subjects older than 60 years of age. In males, spinal stenosis and SDS score

Table 4 Relationships between age, SDS score and QUS parameters and lumbar spinal stenosis

Explanatory variables	Ultrasonographic variable: SOS			Ultrasonographic variable: BUA			Ultrasonographic variable: Stiffness		
	OR	95% CI	P	OR	95% CI	P	OR	95% CI	P
All subjects									
Age	1.06	1.01–1.11	0.022	1.05	1.00–1.10	0.041	1.06	1.01–1.11	0.021
SDS score	1.15	1.01–1.32	0.037	1.17	1.03–1.33	0.019	1.16	1.02–1.32	0.029
SOS-BUA-stiffness	1.02	1.00–1.04	0.014	1.03	0.99–1.06	0.140	1.04	1.01–1.07	0.022
Subjects aged over 60 years									
Age	1.02	0.91–1.14	0.730	1.02	0.90–1.15	0.788	1.04	0.91–1.17	0.583
SDS score	1.22	1.01–1.48	0.037	1.26	1.03–1.56	0.027	1.27	1.03–1.57	0.027
SOS-BUA stiffness	1.03	1.01–1.06	0.010	1.09	1.03–1.17	0.006	1.08	1.03–1.14	0.002
Women									
Age	1.10	1.00–1.22	0.061	1.09	0.99–1.21	0.075	1.10	1.00–1.22	0.060
SDS score	1.29	1.04–1.58	0.018	1.30	1.05–1.60	0.014	1.29	1.05–1.58	0.017
SOS-BUA stiffness	1.01	0.98–1.04	0.534	0.99	0.95–1.04	0.524	1.02	0.97–1.07	0.542
Men									
Age	1.05	0.98–1.14	0.139	1.05	0.98–1.13	0.166	1.06	0.98–1.14	0.130
SDS score	0.98	0.77–1.24	0.867	1.02	0.82–1.26	0.868	0.99	0.79–1.24	0.910
SOS-BUA stiffness	1.03	1.01–1.06	0.010	1.07	1.00–1.15	0.044	1.06	1.01–1.12	0.017

were directly correlated with stiffness. In the women, we found that a larger number of pregnancies was negatively associated with all QUS parameters.

When the SDS score was tested as an outcome variable in a model of multiple linear regression for the study group as a whole, age was directly correlated with SDS score ($P < 0.05$), and higher values of lumbar spine degeneration were noted in the women ($P < 0.05$). No significant relationships between the QUS parameters and SDS scores were noted, except in males, in whom the value of SOS ($P = 0.019$) and calcaneal stiffness ($P = 0.039$) positively predicted the degree of lumbar spine degeneration. The SDS score was positively correlated with a condition of spinal stenosis, except in men.

When we looked at the Oswestry score as an outcome variable, female sex and pain intensity were significantly correlated with this disability index. There was a lack of correlation between the Oswestry score and age, QUS parameters, degree of degeneration in the lumbar spine at imaging, and spinal stenosis.

The relationships of age, SDS score, and QUS parameters with lumbar spinal stenosis as a dependent variable in the multiple logistic regression analysis are shown in Table 4. For the group as a whole, age was directly correlated with a diagnosis of lumbar spinal stenosis. There was also a significant direct association of this diagnosis with the SDS score and QUS parameters. When the sexes were tested separately, the former relationship was missing in the men and the latter in the women.

A summary of the results of the ROC curve analysis for the evaluation of the QUS parameters' ability to predict a condition of spinal stenosis can be found in Table 5. As can be seen, SOS was the most effective QUS param-

Table 5 Summary of ROC curve analysis on the ability of QUS parameters to identify the condition of lumbar spinal stenosis

Parameter	Cut-off value	Sensitivity (%)	Specificity (%)	Area under the ROC curve (95% CI)
All subjects				
SOS	1535.5	52	70	0.614 (0.512–0.716)
Subjects aged over 60 years				
SOS	1532	51	80	0.671 (0.539–0.803)
BUA	125.5	51	84	0.672 (0.539–0.804)
Stiffness	89.5	59	72	0.678 (0.549–0.808)
Men				
SOS	1535.5	79	65	0.752 (0.617–0.887)
BUA	125.5	83	57	0.690 (0.543–0.838)
Stiffness	95	79	61	0.738 (0.600–0.877)
Men over 60 years				
SOS	1532	89	75	0.873 (0.748–0.997)
BUA	125.5	89	67	0.796 (0.626–0.967)
Stiffness	96.5	83	75	0.863 (0.733–0.993)

eter for revealing a condition of lumbar spinal stenosis in the men over 60, whereas BUA was the best variable for excluding such a condition in all subjects over 60 years.

Discussion

Abnormalities on plain lumbar spine radiographs [12] or MRI scans [2,19] can be observed in asymptomatic people. The most frequent coincidental changes found on MRI scans are degenerated or bulging discs, with a 28–52%

prevalence in subjects with no pain [2,19]. Less frequently, lumbar spinal stenosis can also be an incidental finding, particularly in elderly subjects [2, 19]. This is essentially a clinical diagnosis [1,23], but the most severe degrees of narrowing of the spinal canal on imaging tests have been associated with the presence of clinical symptoms [14] and worst outcomes in patients with lumbar pain or neurogenic claudication [20, 21,26]. The problem of abnormal scans in asymptomatic people limits the use of MRI as a screening tool [3]. Therefore, this imaging test should be used only to establish the best treatment strategy in patients with chronic pain [3, 9]. It would be very useful to have a quick and low-cost technique, whose results could be used to predict severe degeneration and stenosis in the lumbar spine in these patients, before we embark on more aggressive diagnostic procedures.

Calcaneal QUS is an adequate tool in the diagnosis of osteoporosis, as it is positively correlated with BMD [6, 13, 22, 25, 31, 33] and with mechanical characteristics of the bone different from BMD, such as elasticity or strength [10,18]. Ultrasound techniques are radiation-free, easy-to-operate, inexpensive and rapid, and they offer a reasonable alternative for the initial evaluation of elderly patients with osteoporosis [13]. Since several studies have reported finding a direct association between high BMD and osteoarthritis in the lumbar spine [7, 15, 16, 27], we carried out this study to find out whether QUS might be useful in predicting the extent of degenerative changes in the lumbar spine of subjects experiencing pain. Our results showed a significant direct correlation between lumbar spinal stenosis and QUS parameters. To the best of our knowledge, this is the first study to report such an association.

Although lumbar spinal stenosis requiring clinical intervention is a diagnosis that is primarily based on history and physical examination findings (or lack thereof), high QUS values in the present study were associated with a decrease in dural sac cross-sectional area below 100 mm² at the most stenotic level – a cut-off point that has been shown to be critical for the development of clinical symptoms [14]. There is no place for QUS in the routine diagnosis of degenerative changes in the lumbar spine of symptomatic subjects, but our study showed the possible clinical relevance of an increase in QUS parameters in subjects experiencing pain who underwent calcaneal ultrasonography for other clinical indications (i.e. osteoporosis).

For the identification of subjects with stenosis, SOS provided higher areas under the ROC curves than either stiffness or BUA, particularly in males over 60 years of age. The sensitivity was sometimes as high as 89%. For all subjects over 60 years of age, BUA was the QUS parameter with the highest ability to exclude a stenosis. In males, we also found a direct correlation of SOS and calcaneal stiffness with the SDS score. Although our review of the literature did not suggest a reason for these relationships, the increase in calcaneal QUS parameters observed in the subjects with higher SDS scores and spinal

stenosis could have been the expression of a change in the characteristics of the subdiscal bone of these subjects.

Dequeker et al. [8] have proposed that an inherited general bone alteration with an increase in biosynthetic activity of the osteoblasts may lead to subchondral bone stiffness and subsequent cartilage damage in osteoarthritis. An increase in mechanical stress on an intervertebral disc has been hypothesised for people with stiffer subdiscal bone [24], and experimental studies have shown that disc degeneration occurs secondary to subchondral bony changes, seen both histologically and radiographically [34]. As there are mutual pathogenic relationships [29], disc degeneration may be responsible for the onset of degenerative lumbar spinal stenosis and facet arthritis. Indeed, we found a positive correlation between stenosis and the SDS, in which disc degeneration plays a basic role.

As other studies have reported [2, 5, 12, 19, 22, 28, 31, 33], we detected a negative effect of aging on ultrasound bony transmission, and a positive association with the SDS score and spinal stenosis. Thus, the correlation between QUS and lumbar spine degeneration observed in our study is independent of age; it is also present when the regression models are adjusted for this explanatory variable.

In the women, no correlation between QUS parameters and degeneration or stenosis in the lumbar spine was noted in the multivariate analysis, but a significant direct correlation of SOS and calcaneal stiffness with spinal stenosis was noted in the group as a whole in the univariate analysis, after adjustment for sex. It is possible that the negative influence of parity on the QUS parameters obscured the correlation between lumbar spine degeneration and QUS in the multivariate analysis, since the number of pregnancies was added to these models as an explanatory variable. Indeed, pregnancy has a negative effect on QUS parameters and it is well known that lactation provokes a 6-month postpartum elevation of bone turnover markers that could set the stage for a subsequent decrease in QUS parameters [32]. Another explanation for the lack of correlation might be the low power of statistical tests, due to the small number of women enrolled.

Our study has two principal shortcomings: the limited number of patients and its cross-sectional design. However, the small sample size did not obscure the correlation observed between the QUS parameters and lumbar spinal stenosis, although weaker associations between these parameters and other explanatory variables might have been discovered in a larger sample. The cross-sectional design did not permit us to assess the possible role of an increase in QUS parameters as a negative outcome predictor in people with LBP or pain in the lower limb. For this purpose, longitudinal studies on this topic are warranted. The main strengths of our study are (1) the use of thorough imaging assessment, with degeneration and stenosis in the lumbar spine being evaluated by unbiased reviewers using numerical scales and physical (dural sac cross-sectional area) measurements, and (2) the capability of a low-cost ultra-

sonic technique to predict the occurrence of stenotic changes in the lumbar spine.

Conclusions

Elderly people with LBP or pain in the lower limb are likely to be near a calcaneal ultrasound machine for the purpose of a diagnosis of osteoporosis. Indeed, ultrasound

techniques are radiation-free, easy-to-operate, inexpensive, and rapid. We do not propose QUS as a screening test prior to or alternative to MRI scans for the diagnosis of lumbar spinal stenosis, but the incidental finding of high QUS values can help to identify symptomatic subjects who need more extensive diagnostic procedures. In males over 60, SOS has a 89% sensitivity to recognise a narrowing of the lumbar spinal canal below 100 mm² of dural sac cross-sectional area.

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