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ORIGINAL ARTICLE

Is bone microarchitecture status of the lumbar spine assessed by TBS related to femoral neck fracture? A Spanish case–control study

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Abstract
Summary Bone mineral density (BMD) as assessed by dual energy X-ray absorptiometry (DXA) constitutes the gold standard for osteoporosis diagnosis. However, DXA does not take into account bone microarchitecture alterations.
Introduction The aim of our study was to evaluate the ability of trabecular bone score (TBS) at lumbar spine to discriminate subjects with hip fracture.
Methods We presented a case–control study of 191 Spanish women aged 50 years and older. Women presented transcervical fractures only. BMD was measured at lumbar spine (LS-BMD) using a Prodigy densitometer. TBS was calculated directly on the same spine image. Descriptive statistics, tests of difference and univariate and multivariate backward regressions were used. Odds ratio (OR) and the ROC curve area of discriminating parameters were calculated.
Results The study population consisted of 83 subjects with a fracture and 108 control subjects. Significant lower spine and hip BMD and TBS values were found for subjects with fractures ($p<0.0001$). Correlation between LS-BMD and spine TBS was modest ($r=0.41$, $p<0.05$). LS-BMD and TBS independently discriminate fractures equally well (OR=2.21 [1.56–3.13] and 2.05 [1.45–2.89], respectively) but remain lower than BMD at neck or at total femur (OR=5.86 [3.39–10.14] and 6.06 [3.55–10.34], respectively). After adjusting for age, LS-BMD and TBS remain significant for transcervical fracture discrimination (OR=1.94 [1.35–2.79] and 1.71 [1.15–2.55], respectively). TBS and LS-BMD combination (OR=2.39[1.70-3.37]) improved fracture risk prediction by 25 %.
Conclusion This study shows the potential of TBS to discriminate subjects with and without hip fracture. TBS and LS-BMD combination improves fracture risk prediction. Nevertheless, BMD at hip remains the best predictor of hip fracture.

Keywords Bone microarchitecture · Bone mineral density · Hip fracture · TBS (trabecular bone score)

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Introduction

One of the main bone disorders is osteoporosis which is characterised by a low bone density (by comparison with normal bone density values) and by a bone microarchitecture alteration [1]. Osteoporosis is a very common disease (200 million women worldwide) and is particularly widespread in post-menopausal women [2]. The main complication of osteoporosis is bone fractures, which can occur at almost any site, which mainly appear on the hip, spine and wrist bones [3].

Bone mineral density (BMD) is considered as the major determinant of bone strength and fracture risk [4, 5]. In

addition, the BMD, as evaluated by dual energy X-ray absorptiometry (DXA), is the gold standard to diagnose and monitor osteoporosis in daily clinical practices using the T-score thresholds that are proposed by the World Health Organization [1]. However, major limitations of BMD assessment exist such as BMD changes and the fracture prediction outcome during treatment [6] or the BMD overlap between subjects with and without subsequent fractures [7, 8]. Half of the overall osteoporotic fractures occur in the normal and the osteopenic zones. Consequently, using only BMD renders it impossible to differentiate subjects at risk of fractures from healthy subjects in these two zones. BMD is only an evaluation of the bone quantity. It does not provide information on bone quality. One way to describe bone quality is to evaluate the bone microarchitecture, which is related to the bone's mechanical resistance [9]. Indeed, for the same amount of bone, more or less mechanically resistant bone structures can exist.

In addition, BMD—as evaluated with a 2D X-ray projection of the bone—estimates the quantity of both trabecular and cortical bone. However, since the cortical bone represents 80 % of the body bone volume, the BMD value was mainly influenced by the cortical bone compartment which has, in comparison to the trabecular compartment, a low bone remodelling process (1:4) [10]. Consequently, one has to wait for a long time (typically years) between two BMD measurements to be able to detect any meaningful changes while dramatic disruption of trabecular bone structure may have occurred [11]. Several studies have shown that trabecular bones contribute to the total bone strength [9, 12, 13] particularly for the femur. Trabecular bone density at the femoral neck decreases twice more than the cortical bone density between 20- and 90-year-old subjects [14]. Besides, it has been shown that about half of the femoral applied load (during gait for example) was supported by the trabecular compartment [15]. Albeit half of the applied load is supported by the trabecular bone, it was shown recently that the contribution of the trabecular versus the cortical bones was marginal (lower than 10 %) with respect to femoral neck strength [16].

Trabecular bone score (TBS) is a new grey-level texture measurement which can be applied to DXA images, by quantifying local variations in grey level [17–19]. TBS is based on the measurement of the experimental variogram derived from the grey-level DXA image. It correlates with standard 3D bone microarchitecture parameters such as connectivity density, trabecular number and negatively with trabecular separation [17–19]. Previous studies have shown the clinical added value of TBS. Indeed, in [20–23], the authors show that TBS was able to discriminate subjects with fracture from subjects without fracture matched for age, BMD or both. In addition, it also is shown that TBS was able to predict major osteoporotic fractures as well as the BMD, though independently [24, 25]. Finally, several studies have shown TBS clinical added value in secondary causes of osteoporosis [26–28].

Our study validated TBS—evaluated at the spine—for femoral neck fracture prediction in patients. We also searched for any additional effect of TBS on and independently of BMD.

Materials and methods

Study subjects

We conducted a retrospective, nonrandom case–control study at the CETIR Grup Mèdic (CGM) site, Barcelona, Spain. CGM is a cluster of medical services specialised in diagnostic imaging. This private institution, founded in 1963, initially focused on nuclear medicine. In 1986, the CETIR launched the first densitometer device using dual photon absorptiometry, in Catalonia, and in 1992, it established the first connection with several DXA densitometers. This densitometry network is supported by a self-designed software giving access to the patient with the clinical, radiologic, laboratory and detailed densitometry scan results.

Women included in this study were referred to CGM by their general practitioner or specialist. CGM facility's trained technicians asked questions following a structured inquiry on demographics, personal and family history of major osteoporotic fractures and/or osteoporosis, history of other comorbidities, gynaecologic and obstetric history and lifestyle. During the observation period, 191 post-menopausal Spanish women, between the ages of 50 and 91 years (66.84± 9.45 years) and with a body mass index (BMI) of 17 to 35 kg/m^2 (26.8±3.3 kg/m^2), were deemed potentially eligible for the study. In all cases, menopausal status was established 1 year after the last menstrual period. This status was confirmed by laboratory test results for 47 % of the selected women, who showed low oestrogen levels. None of the selected women ever received hormone replacement therapies. Subjects were stratified using their fracture status (with fracture and without fracture). Women presenting hip fracture at the femoral neck only were eligible as a fracture case.

These fractures occurred with mild or moderate trauma. In fact, the femoral neck fractures were mostly due to a fall when walking or from a standing position (83 %). Conversely, control subjects did not have previous low-energy fractures (at any site). The subjects were excluded if they either received any treatment and/or had any illness that would impact bones, undergone spinal surgery, severe scoliosis or impact bone condition such as degenerative lumbar spine process, spondylitis or spinal infection. Furthermore, subjects were excluded if they had three or more non-observable lumbar vertebra.

Once both groups of patients established, the assessment of the results was blinded and the groups were not modified by the inclusion, exclusion or substitution of cases or by controls. This study was conducted as prescribed by the latest version of the *Declaration of Helsinki*. Ethical approval was given by the CGM scientific committee for the use of retrospective clinical data and of results of bone measurements in the scope of this study. Each subject was ensured anonymity, which is maintained by using subject-specific numeric codes on all records, including DXA scans and registration cards.

Data collection

We determined the following study subject parameters from DXA scan patient files and records: age, weight, height and BMI, fracture status, BMD, bone mineral content, projected area and spine and femur T-score (total and neck). BMD measurements were performed using a Lunar Prodigy densitometer (General Electric, Milwaukie, MI, USA) and evaluated as the mean of the individual measurements for L1–L4. This evaluation was achieved by an expert in DXA scan interpretation at the CGM. TBS was evaluated in the same measurement regions as those used for BMD using TBS iNsight® V1.8 (Med-Imaps). BMD assessment-excluded vertebrae were also excluded for TBS evaluations at lumbar spine. Clinical data, DXA measurements and TBS values were exported in an Excel file.

Statistical analysis

Statistical analyses were performed using MedCalc software (v11.6.0). Descriptive statistics, including means and 95 % confidence intervals, were estimated for both groups: subject with and without fracture. Parameter correlations were evaluated with the Pearson correlation test. Group differences were assessed with the parametric Student's *T* test or with the nonparametric Mann–Whitney test, depending upon the distribution normality of the tested parameter. A p value<0.05 was considered statistically significant. Univariate and multivariate logistic regressions (backward) were used to investigate possible correlations between independent variables (weight, height, BMI, BMD and TBS) and the status of the fracture. Odds ratio (OR)—expressed for each decrease of 1 standard deviation—and discriminating parameter area of the Receiver Operating Characteristic (ROC) curve (AUC: Area Under the Curve) were calculated. For both these estimates, OR and AUC, 95 % confidence intervals were calculated. Finally, in addition to BMD L1–L4, the TBS clinical added value was analysed with a classification tree approach. This classification was based on a two-step process: first a hip T-score classification then a TBS classification. For the TBS classification, tertile thresholds were used.

Results

Description of the samples

Eighty-three subjects were deemed to have an osteoporosis-related fracture, i.e. a hip fracture at the femoral neck, and were eligible for further analysis. Furthermore, 108 women without fractures constituted the control group. In the patient group presenting hip fractures, 41 % had a hip T-score lower than −2.5 SD, whereas in the control group, only 15 % of the population had a hip T-score lower than −2.5 SD. Descriptive statistics of the study population are presented in Table 1.

Correlation between clinical parameters and TBS and BMD

Moderate correlation—as presented in Table 2—was obtained between TBS and BMD for the spine ($r=0.41$), whereas hip (neck or total) and spine BMD correlation is higher ($0.61 \leq r \leq 0.67$). No significant correlations were obtained between TBS and the height, the weight and the BMI (see Table 2). A negative significant correlation between age and BMD or TBS parameters has been obtained.

Comparison between subjects with and without fractures

Subjects with fractures showed significantly lower weights and BMI than the control subjects ($p<0.05$) while height is not significant. Weight and BMI were border significant ($p=0.028$ and $p=0.033$, respectively). Age was significantly higher for subjects with a fracture than for the control subjects ($p<0.05$). Subjects with a fracture also had significantly lower BMD and TBS at spine than control subjects ($p<0.0001$). Furthermore, subjects with a fracture had a BMD at neck or at total femur significantly lower than control subjects ($p<0.0001$). Results are presented in Table 1.

Detection value of TBS and BMD

We estimated the OR and AUC using a univariate analysis for all parameters. The results were presented in Table 3. For the age parameter, each incremental decrease of 1 standard deviation in BMD L1–L4 was associated an increase of slightly more than 80 % of the odds of presenting a hip neck fracture (OR=1.80 95 % confidence interval=1.31–2.47). The age parameter AUC is 0.673 (0.602–0.739). Also, each incremental decrease of 1 standard deviation of the spine BMD and TBS was associated with more than twice the odds of presenting a transcervical fracture (2.21 [1.56–3.13] and 2.05 [1.45–2.89], respectively). Furthermore, the AUC for BMD and TBS at spine was 0.695 [0.625–0.760] and 0.668 [0.597–0.734], respectively. As expected [29], BMD at neck and at total femur was significantly relevant for fracture discrimination since their OR and AUC were 5.86

Table 1 Characteristics of the study population

	Control subjects (n=108)		Subjects with fracture (n=83)		Normality	p
	Mean	SD	Mean	SD		
Age (years)	64.6	9.8	69.8	8.2	–[a]	0.0001
Height (cm)	153.8	6.1	153.4	6.3	–[a]	0.67
Weight (kg)	64.4	9.0	61.6	8.5	–[a]	0.028
BMI (kg/m^2)	27.2	3.2	26.2	3.4	–[a]	0.033
BMD L1–L4 (g/cm^2)	0.989	0.162	0.87	0.163	–[a]	<0.0001
BMD at neck (g/cm^2)	0.839	0.139	0.689	0.072	–[b]	<0.0001
BMD at total femur (g/cm^2)	0.902	0.154	0.717	0.104	–[a]	<0.0001
TBS L1–L4	1.302	0.107	1.228	0.121	–[b]	0.0001

[a] T test

[b] Mann–Whitney test

[3.39–10.14] and 0.825 [0.764–0.876] and 6.06 [3.55–10.34] and 0.844[0.785–0.892], respectively.

BMD L1–L4 and TBS parameters remained significant when adjusted for age. The OR for BMD L1–L4 and for TBS is 1.94 [1.35–2.79] and 1.71 [1.15–2.79], respectively.

We showed that spine BMD L1–L4 and TBS remained significant cofactors to explain hip neck fractures with a multivariate analysis, using backward analysis, where age, BMI and weight were excluded (p>0.1). The ORs of BMD L1–L4 and TBS cofactors were 1.86 [1.29–2.68] (p=0.001) and 1.66 [1.15–2.40] (p=0.007), respectively. The (BMD L1–L4 + TBS) model was associated with an increase of at least twice the odds (2.39 [1.70–3.37]) of presenting a transcervical fracture. The AUC for the model was 0.714 [0.645–0.777] (Fig. 1).

Clinical approach of a TBS evaluation

Our results obtained with the classification approach, with a focus on subjects with fractures, were presented in Fig. 2. When using femoral neck T-score stratification, 41 % of the fractures occurred in osteoporotic patients and 59 % in osteopenic patients. We classified our population in tertiles of TBS. With this approach, we have found that, for the overall population, 45 % of the fractures occurred in the lowest TBS tertile (TBS≤1.219), and for osteopenic women, that 42.9 % of the fractures were in the lowest TBS tertile. None of the subjects with fractures had a T-score higher than −1 SD.

Using the TBS tertile approach (by selecting subjects in the lowest tertile), 25 % of the overall subjects with a fracture were detected, in addition to those already detected by the T-score thresholding, for a cost of 13 % overdetected control subjects. This result corresponded to a fracture/control ratio of 1.9 (total detected subjects with a fracture in percent divided by the number of overdiagnosed control subjects in percent).

Discussion

The most noticeable result of our case–control study is that TBS—as evaluated at the spine L1L4 by DXA—can discriminate control subjects from femoral neck subjects with

Table 2 Correlation coefficients (r) between parameters

		Age (years)	Height (cm)	Weight (kg)	BMI (kg/cm^2)	BMD at neck (g/cm^2)	BMD at total femur (g/cm^2)	BMD at L1–L4 (g/cm^2)
Height (cm)	r	−0.25**						
Weight (kg)	r	−0.3**	−0.49**					
BMI (kg/m^2)	r	−0.18**	−0.1 NS	0.82**				
BMD at neck (g/cm^2)	r	−0.59**	0.21 NS	0.32**	0.23**			
BMD at total femur (g/cm^2)	r	−0.58**	0.13 NS	0.38**	0.35**	0.93**		
BMD at L1–L4 (g/cm^2)	r	−0.39**	0.14 NS	0.36**	0.32**	0.61**	0.67**	
TBS at L1–L4	r	−0.56**	0.01 NS	0.04 NS	0.04 NS	0.52**	0.54**	0.41**

p<0.05 is considered significant

NS nonsignificant

*p<0.05, **p<0.01

Table 3 Discrimination values of the studied parameters

	Age (ans)	Height (cm)	Weight (kg)	BMI (kg/m^2)	BMD L1–L4 (g/cm^2)	BMD at neck (g/cm^2)	BMD at total femur (g/cm^2)	TBS L1–L4 (−)
OR	1.8	1.07	1.39	1.37	2.21	5.86	6.06	2.05
	[1.31–2.47]	[0.8–1.42]	[1.03–1.88]	[1.02–1.85]	[1.56–3.13]	[3.39–10.14]	[3.55–10.34]	[1.45–2.89]
AUC	0.673	0.531	0.587	0.587	0.695	0.825	0.844	0.668
	[0.602–0.739]	[0.458–0.604]	[0.514–0.658]	[0.514–0.658]	[0.625–0.760]	[0.764–0.876]	[0.785–0.892]	[0.597–0.734]

For each parameter, OR and AUC and their 95 % confidence intervals are presented

fractures, independently of the BMD L1–L4, even after age adjustment (TBS OR=1.71 [1.15–2.79]). This important result is consistent with previous studies [20–23]. Three previous retrospective case–control studies [20–22] demonstrated the added value of TBS against BMD, independently of the BMD threshold. In the first study [20], it was shown that TBS differentiates subjects with and without fractures (age and BMD subject matching) for any BMD stratification (OR=1.95[1.31–2.89], for all fracture types). In the second study [21], 42 fracture subjects were compared to 126 age-matched control subjects, and the clinical TBS added value was established in a low BMD (T-score ≤−1.0). The OR of TBS was evaluated to be 3.20 [2.01–5.08] for vertebral fractures. Finally, in an age-matched case–control study [22] concerning osteopenic subjects (81 fracture subjects compared to 162 age-matched control subjects), the authors concluded that TBS was able to discriminate subjects with and without fractures (OR TBS=2.53 [1.82–3.53]).

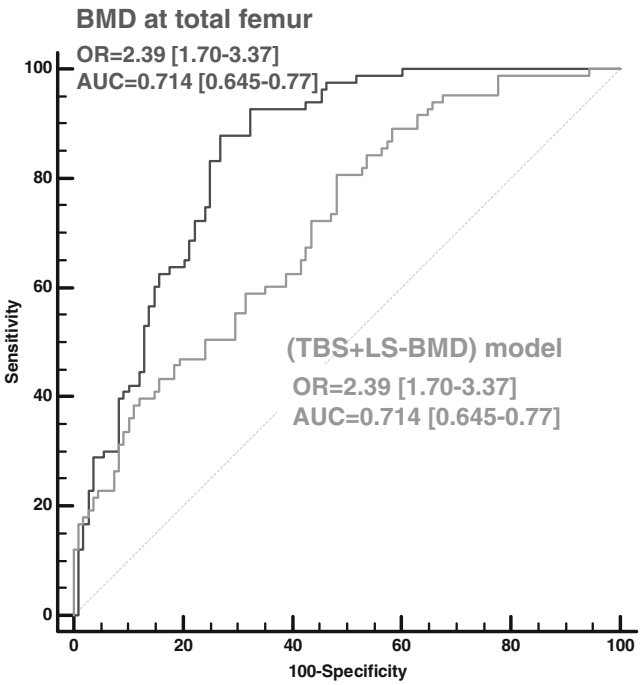

Fig. 1 Area under the receiver operating curve (TBS + BMD) (*grey curve*) determined by the results of the logistic regression analysis, taking TBS and BMD (evaluated at lumbar spine) as input parameters. The *darker curve* represents the ROC curve of BMD at total femur. *OR* odds ratio, *AUC* area under the curve

The OR of TBS we obtained is lower than those found in these three previous studies [20–22]. We explain this result by the fact that only femoral neck fractures are taken into account. Indeed, femoral neck fragility, in comparison with vertebral fragility, is linked to both cortical and trabecular bone [16], whereas vertebral fragility is mainly linked to trabecular bone status.

TBS is evaluated at the anteroposterior spine L1–L4 and not at the femur. A significant difference between lumbar vertebrae and femur compositions exists since lumbar vertebrae are mainly composed of trabecular bones (72 %) whereas the femur is composed of both trabecular (25–50 % of the proximal femur) and cortical bones [30, 31]. Furthermore, TBS only assesses the trabecular bone status. Consequently, the cortical compartment contribution to bone strength is not assessed by TBS. It was shown that about half of the femoral applied load was supported by the cortical compartment [15], in agreement with results previously obtained [30]. Using quantitative computed tomography (QCT) and DXA, authors evaluated the role of the proximal femur compact bone to bone strength. Their results showed that 43 % of the femoral failure load is explained by QCT geometric variables, whereas 72 % is explained by densitometric variables. Furthermore, femoral failure load variance was explained at 52 % by the trabecular variables, whereas 59 % of this variance was explained by cortical variables. These results [15, 30] were in contradiction with those obtained in [16]. In this last study, authors showed a marginal contribution (lower than 10 %) of the trabecular bone to the femoral neck strength with respect to the cortical bone contribution. However, it is difficult to compare these results since the mechanical testing methodologies used were different. This is why TBS OR is lower for femur fracture evaluation at spine. A similar conclusion can be made for BMD since it has been also demonstrated that femur BMD is heterogeneous in both cortical and trabecular bones [32]. In addition, it has been shown that trochanteric BMD is a better predictor of inter-trochanteric femoral fractures than femoral neck BMD [33].

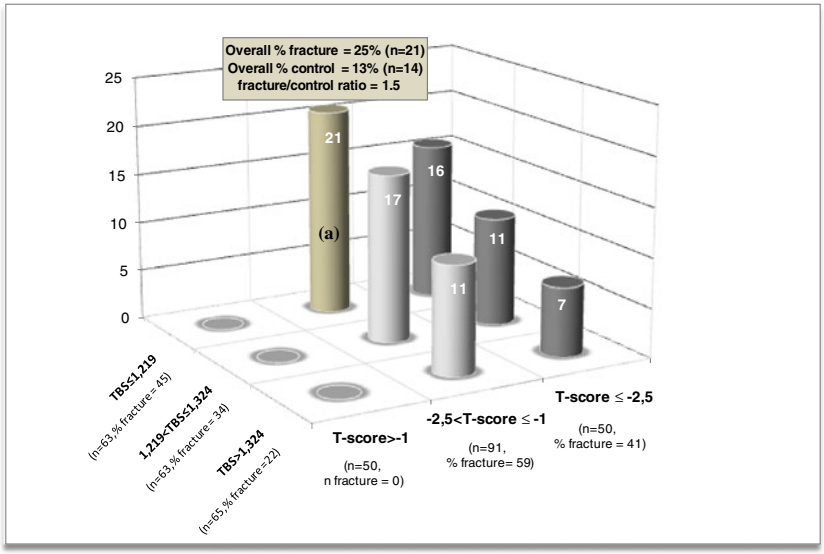

Fig. 2 Results of the two-step classification approach for subjects with hip fractures (n=83). The first classification step concerns a T-score at neck stratification with three zones: T-score ≤ −2.5SD, −2.5SD <T-score ≤ −1 SD and T-score > −1SD. The second step is based on a tertile TBS classification with the following thresholds: TBS≤1.219, 1.219<TBS≤1.324 and TBS>1.324. The number of subjects (n: control and subjects with hip fractures) and the fracture rate in percent (percent of fractures) were expressed for each subcategory. The number of subjects with hip fractures is plotted (*white text*) on the rod of each subcategory. The (a) rod represents osteopenic subjects with a TBS≤1.219. The overall fracture or control percent represents the number of subjects with hip fractures or control subjects in this subcategory divided by the overall subjects with hip fractures (n=83) or control subjects (n=108). Subjects with hip fractures/control subject ratio is expressed by the division of the number of subjects with hip fractures by the number of control subjects in this subcategory

Combining TBS and BMD L1–L4 in a model (using a backward logistic regression) improved fracture prediction since the OR of the model was 2.39 [1.70–3.37], whereas for BMD L1–L4 and TBS, the ORs are 1.86 [1.29–2.68] and 1.66 [1.15–2.40], respectively. In our model, TBS and BMD L1–L4 cofactors remained significant (p=0.007 and p=0.001, respectively) while age, weight and BMI were excluded (p>0.1). This result was in accordance with previous results obtained in [20–24]. In [24], the authors, in a reanalysis of the Manitoba cohort (29,407 women aged 50 years and older), showed that TBS and BMD predicted fractures equally well and independently. The combined model predicted fractures much better than parameters alone, whatever the fracture stratification type even after an age adjustment. In [24], as in previous studies [20–28], this improvement of fracture prediction was explained by the moderate correlation existing between spine TBS and BMD L1–L4 (r=0.41). In other words, subjects with hip fractures discriminated with BMD L1–L4 were a different population than those discriminated with TBS. In our study, the predictive value of BMD at femoral neck (5.86 [3.39–10.14]) or at total femur (6.06 [3.55–10.34]) overrides all other predictive parameters such as spine BMD (2.21 [1.56–3.13]), TBS (2.05 [1.45–2.89]) or age (1.80 [1.31–2.47]) even after combination of these parameters into a prediction model. Results obtained in this study for BMD at hip are consistent with those obtained in the literature [33–35]. Particularly, in a study dealing with hip fracture risk assessment in Spanish population, Alonso et al. [33] obtained a quite similar but lower odds ratio for femoral neck BMD than the one obtained in our study: 4.45 [3.11–6.36] versus 5.86 [3.39–10.14]. In [35], the authors obtained an odds ratio of 5.29 [1.87–18.99] for femoral neck BMD for hip fracture discrimination in a cohort of 440 Caucasian postmenopausal Italian women. However, these results are in contrast with those obtained in [4]. In this meta-analysis, involving 12 worldwide cohorts, authors obtained an odds ratio of 2.88 [2.31–3.59] for femoral neck BMD in women aged 65 years for hip fracture discrimination. BMD at hip is the best predictor for hip fracture in men and women [4, 36]. Hip BMD ability to predict fragility fracture of the hip can be explained by its strong association with bone section modulus and bone buckling ratio modifications [37, 38] due to homeostatic process of bone expansion with ageing [38]. These bone modifications are specific to the femoral joint, and thus, no measurement performed at another site could take these specificities into account in order to assess fracture risk.

To recapitulate, TBS enables, from a spine evaluation, the discrimination of subjects with transcervical fractures. In addition, TBS in combination with BMD L1–L4 noticeably improves femoral neck fracture prediction, with a better

performance than TBS or BMD L1–L4 alone. These results encouraged us to highlight the use of TBS from a clinical point of view. Hence, we built a decision tree based on two stratification steps (a BMD stratification followed by a TBS stratification). For BMD, hip T-score stratification (with WHO thresholds) was used, while a tertile approach was used for TBS. The two thresholds obtained for TBS were 1.219 for the lowest tertile and 1.324 for the highest tertile (see Fig. 2). The osteoporotic zone contained 41 % of the overall subjects with fractures and 14.8 % of the overall control subjects, whereas 59 % of the overall subjects with fractures were in the osteopenic zone. Focusing on this last zone (n=91), 25 % of the overall subjects with fractures had a TBS in the lowest tertile while only 13 % of the overall control subjects were in this tertile. Using this two-step approach, it appeared that with our TBS analysis, 66 % of the overall fracture subjects could have been predicted and potentially treated. These results are in agreement with those previously reported [24–26]. In a study concerning the fracture prediction in 140 rheumatoid arthritis subjects with secondary osteoporosis taking or not a glucocorticoid treatment, Breban et al. [26] showed that 8 of 13 osteopenic subjects with fractures had a TBS in the lower TBS subdivision. Boutroy et al. [25], in the OFELY cohort reanalysis, showed that 37 % of the fractures of osteopenic women were in the lowest tertile of TBS. Similar results were obtained by Hans et al. [24] in the Manitoba cohort reanalysis since 38 % of the fractures incorrectly classified by BMD were identified when using TBS.

As shown by the current and previous studies, the use of TBS, in addition to BMD, induces an overdiagnosis and thus an overtreatment due to an overestimation of subjects at risk of fracture. However, considering this two-step classification approach, (1) detection of the subject with a fracture versus overdiagnosed control subject ratio is advantageous (1.9 in this study and 1.7 for the others studies); (2) it is clear that the most important is to diagnose and treat patients with a high risk of fracture.

This study is not without limitations. The most relevant is that this is a retrospective case–control study. Hence, we cannot directly imply causative association between a low TBS value and an osteoporotic femoral neck fracture. However, in [24], authors showed that TBS predicts osteoporotic fractures (for vertebral, femoral and all osteoporotic fracture types) equally as well as the BMD and independently. The second limitation is linked to the fact that TBS is evaluated at the anteroposterior spine L1–L4 and not at the femur. We can expect that an evaluation at the hip should improve TBS prediction rates and that TBS in combination with BMD, both evaluated at the hip, should give the best prediction results. Considering the clinical point of view of using TBS, this first approach should be confirmed by a multicentric prospective study. In addition, it is necessary to evaluate the balance between the cost of the overtreatment due to the use of TBS in complement with BMD and the cost of osteoporotic fractures as it has been done for WHO FRAX® [39].

In conclusion, this study shows the promising potential of TBS to discriminate subjects with and without fractures of the hip for femoral neck fracture types. TBS improves hip fracture prediction of the spine BMD when it is combined. Nevertheless, in our study—as previously reported in several other studies—BMD at femoral neck (or at total femur) is the best predictor of hip fracture and overrides all other parameters. Further investigations have to be done in order to develop and evaluate TBS at femur in combination or independently of hip BMD.

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