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Original Article

Dual Energy X-Ray Absorptiometry-Based Assessment of Male Patients Using Standardized Bone Density Values and a National Reference Database

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Abstract

Dual energy X-ray absorptiometry (DXA) measurements from different manufacturers provide different bone mineral density (BMD) values and derived T-scores and Z-scores. These differences result partly from technical differences in the algorithms for the determination of bone mineral content and bone area and partly from the use of different manufacturer-derived reference databases. The present study was to implement a uniform expression of BMD in all male patients by using standardized BMD (sBMD) values and referring to a newly established national male reference sample. In 8 bone densitometry centers throughout Belgium 229 young healthy men were measured on Hologic (Bedford, MA) or GE-Lunar (Madison, WI) bone densitometers. Quality control procedures were implemented and site cross-calibration performed using the European Spine Phantom. Absolute BMD values were converted to standardized values by validated formulas (sBMD). Clinically acceptable between-center differences were noted. No discrepancy was observed in terms of mean sBMD and standard deviations at the lumbar spine and proximal femur between the Belgian and the US reference populations. Region-specific sBMD thresholds for the diagnosis of male osteoporosis were calculated. The current data provide a basis to implement a nation-wide, uniform expression of BMD in male patients and allow harmonization of the BMD-based diagnosis and treatment of osteoporosis in men.

Key Words: Cross-calibration; dual energy X-ray absorptiometry (DXA); male osteoporosis; reference ranges; standardized bone mineral density.

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[a]BBC is a national nonprofit scientific organization devoted to promoting bone research and the awareness of osteoporosis—its board members are listed in Appendix A.

[b]NEMO is a Thematic Network supported by the European Commission under contract QLK6-CT-2002-00491—its participants are listed in Appendix B.

Introduction

Male osteoporosis and osteoporosis-related fragility fractures are increasingly being recognized as an important medical condition *(1–3)*. Approximately 1 in 5 men is affected, with about 1 in every 4 or 5 hip fractures occurring in men. The total direct costs associated with male osteoporosis have been estimated at some $ 40 billion (over € 30 billion) *(4)*. As in women, fragility fractures in men are associated with significant morbidity, functional consequences, and mortality. Excess mortality in men with osteoporosis is even higher than in women *(5)*. Although male osteoporosis has been studied less extensively than postmenopausal osteoporosis, recent prospective data have confirmed that, among other factors, low bone mineral density (BMD), as assessed by dual energy X-ray absorptiometry (DXA), is predictive of future fracture risk in both sexes *(6–8)*. In this regard, DXA should be an integral part of any fracture risk assessment in men. Recently, the International Society of Clinical Densitometry (ISCD) published a position paper on the use of DXA in men *(9)*, recommending a central diagnostic role for DXA. In men over the age of 65 yr, the ISCD considered a DXA T-score below −2.5 (based on a male reference database) to be sufficient to allow the diagnosis of osteoporosis. In those under the age of 65 yr, additional risk factors for fracture should be taken into account *(10,11)*.

One of the main problems with DXA values obtained on different devices is that these cannot be directly compared. The absolute values (g/cm^2) obtained on equipments from Hologic or Lunar are different, because of differences in calibration and bone-edge detection algorithms, and from these absolute values, T-scores will be calculated using different manufacturer-derived databases. To avoid these inconsistencies and to provide a uniform basis for patient assessment in Belgium, the Belgian Bone Club (BBC)—the Belgian national osteoporosis society—recently implemented a uniform expression of BMD in Belgian postmenopausal patients, by converting each manufacturer's absolute BMD to standardized BMD (sBMD) values and by establishing 1 single national reference range *(12)*. In the current study, we pursued a similar approach in men, to establish uniform thresholds for the diagnosis of male osteoporosis.

Materials and Methods

Study Subjects

A total of 229 healthy young-adult men were enrolled in 8 different clinical bone densitometry centers across Belgium. All participants had to be healthy Caucasians, between 20 and 37 years of age, and provided informed consent. They were recruited partially by a population-based approach in university hospital driven studies (n = 100) and partially from hospital employees, family members, or sporadic volunteers if no population-based programs were available (n = 129). To ensure a normal "health status," the following exclusion criteria were applied: (1) a history of medical conditions known to affect BMD (including diabetes mellitus, hyperthyroidism, hyperparathyroidism, immobilization, rheumatoid arthritis, osteomalacia, gastrectomy, intestinal resection, celiac disease, anorexia nervosa, and hypogonadism), (2) any current or prior use of drugs known to affect bone metabolism (including glucocorticoids, bisphosphonates, and thyroxine), and (3) a body mass index (BMI) exceeding 38 kg/m^2. Date of birth, standing height, and weight were recorded.

BMD Measurements

BMD values (g/cm^2) were measured by DXA at the lumbar spine (ROIs: L2–L4 and L1–L4) and the proximal femur (regions of interest: femoral neck and total hip region), using devices from Hologic or GE-Lunar. In 139 men (recruited in 3 centers), BMD was measured with Hologic fan-beam scanners (2 QDR 4500As and 1 Delphi), whereas Lunar scanners were used to assess BMD in 90 men from 5 different centers (4 pencil-beam: 2 DPX-Ls, 2 DPX-NTs, and 1 fan-beam scanner: Prodigy). Posteroanterior lumbar spine and hip BMD were measured using standard procedures specified by each manufacturer for scanning and analysis. All machines were calibrated by the individual manufacturers and quality controls performed according to their standards, as described in the respective manuals of standard operating procedures. Intersite calibration differences were measured by 10 repeat measurements of a European spine phantom (ESP026; QRM, Erlangen, Germany). The in vitro coefficient of variation (CV) of the BMD was $<1\%$ on Hologic and $<2\%$ on Lunar devices.

Calculation of sBMD

Standardized BMDs were calculated using previously established cross-calibration equations *(13–17)*, providing results in internationally accepted utilization units. To discriminate the manufacturer-specific BMD values from the sBMD values, the former values, by convention, were expressed in grams per square centimeter and the latter in milligrams per square centimeter. The formulas are given in Appendix C. These formulas resulted from regression analyses expressing the best fit between devices specific absolute BMD values in human studies confirmed by in vitro phantom measurements.

The Belgian reference sample was compared to well accepted US standards. For the lumbar spine (L2–L4/L1–L4), BMD reference values provided by the manufacturer *(18,19)* and for the proximal femur values (total and femoral neck), the updated data from the NHANES III survey *(20)* were used.

Statistical Analysis

All data were expressed as mean ± SD. Mean BMD values and thresholds were compared using Student's *t*-test. All statistical tests were 2-sided and comparisons were considered significant at a p value of 0.05 or less.

Results

The mean values and %CV of the repeated ESP assessments (area, bone mineral content [BMC], and BMD) are presented in Table 1. Standardization of the device-specific BMD to sBMD values markedly reduced the range of the intersite variability. The global CVs, calculated from all site phantom measurements were 6.2% and 1.7%, respectively. The median age (yr) of the study population (n = 229) (28.4; P_{25}–P_{75}: 25.0–31.7). Other baseline characteristics (mean ± SD) were as follows: height (cm) (180.5 ± 6.8), weight (kg) (76.5 ± 11.2), and BMI (kg/m^2) (23.5 ± 3.0).

The BMD and sBMD values for the study population are presented in Fig. 1, and Tables 2 and 3 for the lumbar spine (L2–L4 and L1–L4, respectively) and in Table 4 for the total hip and femoral neck region. The Belgian peak bone mass values, including mean values ± standard deviations (SDs), were not significantly different from the US reference values

Table 1
Bone Mineral Assessments on European Spine Phantom (ESP026) by Study Centers

Location	Area L2–L4 (cm^2)	BMC L2–L4 (g)	BMD L2–L4 (g/cm^2)	sBMD[a] (mg/cm^2)	sBMD[b] (mg/cm^2)
Study Center					
Lunar 1 DPX-L					
Mean	27.61	30.45	1.102	1050	1046
%CV	0.8	0.9	0.6	0.6	0.6
Lunar 2 DPX-NT					
Mean	27.97	30.43	1.087	1035	1031
%CV	0.7	0.6	0.7	0.7	0.7
Lunar 3 Prodigy					
Mean	28.17	30.83	1.094	1042	1038
%CV	0.2	0.5	0.4	0.4	0.5
Lunar 4 DPX					
Mean	26.71	30.28	1.134	1082	1076
%CV	0.8	0.7	0.7	0.7	0.7
Lunar 5 DPX-NT					
Mean	27.87	29.84	1.071	1020	1015
%CV	0.8	0.5	0.6	0.6	0.6
Hologic 1 QDR4500					
Mean	29.57	28.62	0.968	1041	1039
%CV	0.8	1.1	0.8	0.8	0.8
Hologic 2 QDR4500					
Mean	29.50	28.36	0.961	1034	1032
%CV	1.0	0.8	0.4	0.4	0.4
Hologic 3 Delphi					
Mean	29.29	28.34	0.971	1044	1042
%CV	1.2	1.1	0.6	0.6	0.6
Manufacturer					
Lunar					
Mean	27.67	30.36	1.098	1045	1041
%CV	2.0	1.23	2.0	2.0	2.1
Hologic					
Mean	29.43	28.41	0.965	1038	1035
%CV	1.1	1.1	0.6	0.6	0.6
Global[c]					
Mean	28.25	29.71	1.046	1041	1038
%CV	3.4	3.3	6.2	1.7	1.7

Site- and device-specific values are means of 10 assessment of ESP026.
[a]sBMD calculation according to the formula reported in Ref. *(13)*.
[b]sBMD calculation according to the formula reported in Ref. *(14)*.
[c]Global reports the data for all site phantom measurements pooled together.

(18–20). Only the lumbar spine BMD values of the Hologic subpopulation were slightly but statistically significantly lower in the Belgian male sample (n = 139).

According to the formula of Genant et al. *(13)*, sBMD (based on Hologic and Lunar values) at the lumbar spine (L2–L4) was 1165 ± 114 mg/cm^2 in the BBC reference young sample and 1190 ± 116 mg/cm^2 in the US reference young population, respectively (NS). When calculated according to the formula of Hui et al. *(14)*, the corresponding values of sBMD at the lumbar spine (L2–L4) were 1162 ± 122 mg/cm^2 and 1187 ± 116 mg/cm^2 for the Belgian and US reference populations, respectively (NS). Similarly, the values of sBMD at L1–L4 region were not different in the Belgian sample and US population (Table 3).

At the total hip (Hologic and GE-Lunar based), sBMD values according to the formula of Hanson *(15)* were 1051 ± 128 mg/cm^2 and 1042 ± 127 mg/cm^2 in the BBC and US reference populations, respectively (NS). When using the formula of Lu et al. *(16)*, sBMD values were 1052 ± 140 mg/cm^2 and 1040 ± 138 mg/cm^2, respectively, again not statistically different between the 2 populations.

Using similar WHO criteria as previously published for women *(1)* and in line with a recent ISCD position statement *(9)*, thresholds were calculated to define sBMD values of 1 and 2.5 SD below the average male peak bone density, respectively. Both at the lumbar spine and the total hip, thresholds based on the BBC and the US normal values were similar (Table 5). At the hip, standardization is complicated because femoral neck BMD is measured by different manufacturer-specific algorithms (Table 4). The femoral neck BMD standardization would have to be based on a cross-calibration. This does not offer full statistical guarantees and the agreement coefficient kappa will be weak *(17)*. If we accept small discrepancies, the values for the femoral neck can be expressed according to the formulas of Lu et al. *(16)* and/or Simmons et al. *(17)* to normalize femoral neck BMD. The standardized mean ± SD and threshold values for the femoral neck are summarized in Table 5. The values are not statistically or clinically different between the calculations derived from the BBC or US reference data set.

Overall, 5 men (2.1%) had a BMD T-score lower than −2.5 at the spine (L2–L4), compared to 4 (1.7%) men after standardization. The corresponding numbers for L1–L4 are 3 and 1, respectively. Similarly, standardization induced no significant shift in diagnostic category when assessing BMD at the total hip (2/1) or femoral neck (0/1) region.

Discussion

There has been great interest in standardizing BMD values, to allow a formal comparison between values obtained on devices from different manufacturers *(20)* in different countries. A lack of standardization has resulted in differences in reported young normal SD scores or T-scores between Hologic, Lunar, and Norland systems *(21–23)*. In the context of this study, differences of up to 5.6% were observed

Table 2
Lumbar Spine (L2–L4) BMD and sBMD Values (mean ± SD) of Healthy Young Males (n = 229) According to the Manufacturers

	L2–L4 BMD (g/cm^2)			L2–L4 sBMD (mg/cm^2) according to Genant et al. *(13)*			L2–L4 sBMD (mg/cm^2) according to Hui et al. *(14)*		
Manufacturer	Belgian reference population (BBC)	US reference population	Difference *p*	Belgian reference population (BBC)	US reference population	Difference *p*	Belgian reference population (BBC)	US reference population	Difference *p*
Hologic	1.066 ± 0.105	1.115 ± 0.110	0.005	1147 ± 113	1199 ± 118	0.005	1143 ± 113	1194 ± 118	0.015
Lunar	1.242 ± 0.120	1.240 ± 0.120	NS	1183 ± 115	1181 ± 114	NS	1181 ± 114	1179 ± 114	NS
Global	—	—	—	1165 ± 114	1190 ± 116	NS	1162 ± 112	1187 ± 116	NS

Abbr: sBMD, standardized BMD (see Appendix C); NS, not significant.
p Values from Student's *t*-test (significance level at $p < 0.05$).

Table 3
Lumbar Spine (L1−L4) BMD and sBMD Values (mean ± SD) of Healthy Young Males (n = 229) According to the Manufacturers

	L1−L4 BMD (g/cm^2)			L1−L4 sBMD (mg/cm^2) according to Genant et al. *(13)*			L1−L4 sBMD (mg/cm^2) according to Hui et al. *(14)*		
Manufacturer	Belgian reference population (BBC)	US reference population	Difference *p*	Belgian reference population (BBC)	US reference population	Difference *p*	Belgian reference population (BBC)	US reference population	Difference *p*
Hologic	1.046 ± 0.104	1.091 ± 0.110	0.001	1139 ± 114	1173 ± 118	0.001	1122 ± 112	1169 ± 118	0.002
Lunar	1.216 ± 0.119	1.220 ± 0.120	NS	1158 ± 114	1162 ± 114	NS	1156 ± 114	1160 ± 114	NS
Global	—	—	—	1149 ± 114	1168 ± 116	NS	1139 ± 113	1165 ± 116	NS

Abbr: sBMD, standardized BMD (see Appendix C); NS, not significant.
p Values from Student's *t*-test (significance level at $p < 0.05$).

Table 4
Total Hip and Femoral Neck BMD and sBMD Values (mean ± SD) of Healthy Young Males (n = 229) According to the Manufacturers

	BMD (g/cm^2)			sBMD (mg/cm^2) according to Hanson *(15)*			sBMD (mg/cm^2) according to Lu et al. *(16)*		
Manufacturer	Belgian reference population (BBC)	US reference population	Difference *p*	Belgian reference population (BBC)	US reference population	Difference *p*	Belgian reference population (BBC)	US reference population	Difference *p*
Total hip									
Hologic	1.026 ± 0.149	1.033 ± 0.151	NS	1040 ± 127	1047 ± 158	NS	1040 ± 138	1047 ± 153	NS
Lunar	1.122 ± 0.134	1.090 ± 0.130	NS	1067 ± 129	1036 ± 124	NS	1064 ± 142	1033 ± 123	NS
Global	—	—	—	1051 ± 128	1042 ± 127	NS	1052 ± 140	1040 ± 138	NS
Femoral neck				Ref *(16)*	Ref *(16)*		Ref *(17)*	Ref *(17)*	
Hologic	0.892 ± 0.130	0.930 ± 0.136	NS	987 ± 144	1029 ± 150	NS	1008 ± 192	1017 ± 198	NS
Lunar	1.100 ± 0.131	1.090 ± 0.130	NS	978 ± 120	998 ± 119	NS	1020 ± 89	1010 ± 88	NS
Global	—	—	—	997 ± 132	1014 ± 135	NS	999 ± 133	1014 ± 148	NS

Abbr: sBMD, standardized BMD (see Appendix C); NS, not significant.
p Values from Student's *t*-test (significance level at $p < 0.05$).

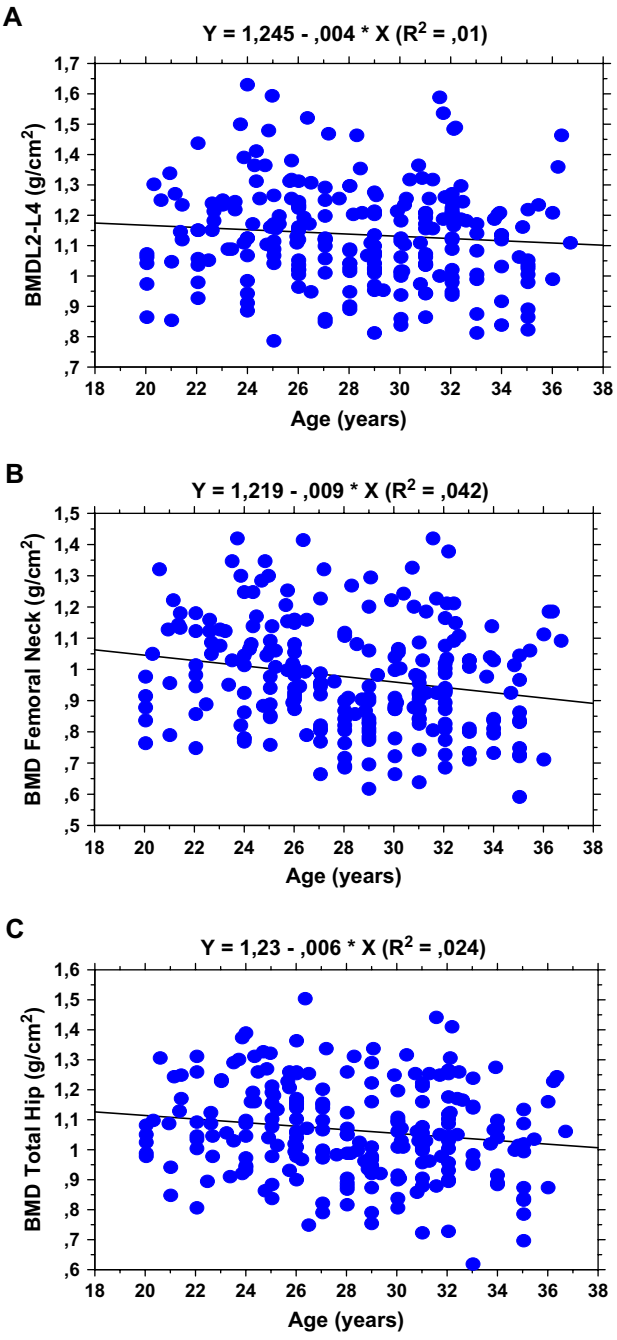

Fig. 1. Region-specific BMD values (g/cm^2) in healthy young men (n = 229) in relation to age. (**A**) L2−L4, (**B**) femoral neck, (**C**) total hip.

between crude mean BMD values obtained on a single ESP circulated among the participating DXA centers (Table 1).

To partly address these inconsistencies, the International Committee for Standards in Bone Measurement developed formulas for the conversion of manufacturer-derived absolute BMD values (expressed in g/cm^2) into sBMD values (expressed in mg/cm^2) *(13−17)*. Compared to the ESP driven standardization method, as developed by the Committee d'Actions Concerte—BioMedical Engineering (COMAC-BMC) *(24)*, these formulas are generated by the International Committee for Standards in DXA following a study with more than 100 subjects and are considered as the preferred method. Although these formulas were generated from a study of females, a realistic assumption in the present study was that these also applied for men, as no published male standardization formulas exist. After conversion to sBMD values, the intersite variability in ESP data was reduced to less than 2% (Table 1).

Various European studies have provided evidence to suggest that the use of US reference ranges (as opposed to local reference values) might have a significant impact on the prevalence of osteopenia or osteoporosis *(25,26)*. To provide a uniform basis for the diagnosis of male osteoporosis we established, although with a limited number, a national male reference sample, similar to what we did in women *(12)*. A single, nation-wide reference sample avoids the inconsistencies that result from the use of different, manufacturer-derived reference populations and from the use of different statistical approaches to derive T-scores from these reference values *(21)*. Overall, our findings in men showed similar peak BMD values and SDs in the Belgian young adults compared to the US reference population, both on Hologic and GE-Lunar, with the exception of Hologic lumbar BMD. The isolated lower (s)BMD values at L2−L4 and L1−L4 on the Belgian fan-beam Hologic densitometers compared to those on the more ancient US pencil-beam Hologic (respectively, 4.5% and 3.0%) may be most probably due to true population differences, as firstly in Hologic's database the reference populations for the spine and proximal femur BMD are different and secondly well established fan-beam vs pencil-beam cross-calibration studies usually report differences less than 2% *(27,28)*. Finally, the pertaining small difference (respectively, 2.1% and 1.6%) between the global Belgian and US device independent sBMD mean values is considered not to be of major clinical relevance.

The ultimate goal of the BBC's efforts in women *(12)* and—as reported here—in men, is to develop a national framework for diagnosing osteoporosis and its treatment. In Belgium, as in many other European countries, antiresorptive agents such as bisphosphonates or selective estrogen receptor modulators (SERMs) are primarily used in postmenopausal patients with DXA-documented osteoporosis (unless they have already suffered vertebral fractures). Mainly, the T-score concept (expressing the patients' results as the number of SD for the sex-specific peak bone mass) has been accepted for the diagnostic categorization and later on proposed for treatment guideline, and/or reimbursement as provided by multiple clinical trials. Recent evidence supports the concept that agents such as alendronate *(29)*, risedronate *(30)*, and teriparatide *(31)* are likely to reduce fracture risk to a similar extent in both sexes.

By calculating sBMD values and by providing national reference values, osteoporosis can be uniformly diagnosed across different centers using different devices, provided that strict quality control measures are implemented.

Table 5
Standardized BBC Thresholds for Osteopenia (T-Score < -1), Osteoporosis (T-Score < -2.5) at the Lumbar Spine, Total Hip, and Neck

	sBMD (mg/cm^2)			sBMD (mg/cm^2)				
	Based on BBC reference date			Based on US reference date			Difference	
Location	Genant et al. *(13)*	Hui et al. *(14)*	Difference p	Genant et al. *(13)*	Hui et al. *(14)*	Difference p	BBC vs US *(13)*	BBC vs US *(14)*
Lumbar spine								
L2−L4								
T-score −1.0	1051	1050	NS	1074	1071	NS	NS	NS
T-score −2.5	880	882	NS	900	897	NS	NS	NS
L1−L4								
T-score −1.0	1035	1026	NS	1052	1049	NS	NS	NS
T-score −2.5	864	857	NS	878	875	NS	NS	NS
	Hanson *(15)*	Lu et al. *(16)*		Hanson *(15)*	Lu et al. *(16)*		BBC vs US *(15)*	BBC vs US *(16)*
Total hip								
T-score −1.0	923	912	NS	915	902	NS	NS	NS
T-score −2.5	731	703	NS	724	695	NS	NS	NS
	Lu et al. *(16)*	Simmons et al. *(17)*		Lu et al. *(16)*	Simmons et al. *(17)*		BBC vs US *(16)*	BBC vs US *(17)*
Femoral neck								
T-score −1.0	865	866	NS	879	866	NS	NS	NS
T-score −2.5	667	667	NS	677	644	NS	NS	NS

Abbr: sBMD, standardized BMD (see Appendix C); NS, not significant.
p Values from Student's t-test (significance level at $p < 0.05$).

Introducing a more standardized approach may facilitate the diagnosis and treatment of male osteoporosis. In line with recommendations from the IOF *(32)*, the NOF *(33)*, and the ISCD *(10)*—the most rational approach is a selection of individuals for bone densitometry on the basis of age and other clinical risk factors.

Limitations of the present male study are the relatively small sample size, the nonuniform criteria for their recruitment, and the absence of Norland densitometer sites able to participate and recruit a valuable number of healthy male volunteers.

We conclude that it is possible to implement a nation-wide, uniform expression of BMD and to harmonize the DXA-based diagnosis of osteoporosis and the drug therapy in women and men with osteoporosis.

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References

1. Kanis JA, Melton LJ 3rd, Christiansen C, Johnston CC, Khaltaev N. 1994 The diagnosis of osteoporosis. J Bone Miner Res 9:1137−1141.
2. Gullberg B, Johnell O, Kanis J. 1997 World-wide projections for hip fracture. Osteoporos Int 7:407−413.
3. Kanis JA, Johnell O, Oden A, et al. 2000 Longterm risk of osteoporotic fracture in Malmö. Osteoporos Int 11:669−674.
4. Kanis JA, Johnell O, on behalf of the Committee of Scientific Advisors of the International Osteoporosis Foundation 2005 Requirements for DXA for the management of osteoporosis in Europe. Osteoporos Int 16:229−238.
5. Poor G, Atkinson EJ, O'Fallon WM, Melton LJ III. 1995 Determinants of reduced survival following hip fractures in men. Clin Orthop Relat Res 319:260−265.
6. De Laet CEDH, van Hout BA, Burger H, Hofman A, Pols HAP. 1997 Bone density and risk of hip fracture in men and women: a cross-sectional analysis. BMJ 315:221−225.
7. Schuit SCE, van der Klift M, Weel AEAM, et al. 2004 Fracture incidence and association with bone mineral density in elderly men and women: the Rotterdam study. Bone 34:195−202.
8. Haentjens P, Johnell O, Kanis JA, et al., on behalf of the Network on Male Osteoporosis in Europe (NEMO) 2004 Evidence from data search and life-table analyses for gender-related differences in absolute risk of hip fracture after Colles' or spine fracture: Colles' fracture as an early and sensitive marker of skeletal fragility in Caucasian men. J Bone Miner Res 19: 1933−1944.
9. Writing Group for the ISCD Position Development Conference. 2004 Diagnosis of osteoporosis in men, premenopausal women and children. J Clin Densitom 7:17−26.
10. Writing Group for the ISCD Position Development Conference. 2004 Indications and reporting for dual energy X-ray absorptiometry. J Clin Densitom 7:37−44.
11. National Osteoporosis Foundation 2003 Physician's guide to prevention and treatment of osteoporosis. NOF, Washington DC.
12. Boonen S, Kaufman JM, Reginster JY, Devogelaer JP. 2003 Patient assessment using standardized bone mineral density values and a national reference database: implementation uniform thresholds for the reimbursement of osteoporosis treatments in Belgium. Osteoporos Int 14:110−115.
13. Genant HK, Grampp S, Glüer CC, et al. 1994 Universal standardization for dual X-ray absorptiometry: patient and phantom cross-calibration results. J Bone Miner Res 9:1503−1514.
14. Hui SL, Gao S, Zhou X-H, et al. 1997 Universal standardization of bone density measurements: a method with optimal properties for calibration among several instruments. J Bone Miner Res 12: 1463−1470.
15. Hanson J. 1997 Standardization of femur BMD. J Bone Miner Res 12:1316−1417.
16. Lu Y, Fuerst T, Hui S, Genant HK. 2001 Standardization of bone mineral density at femoral neck, trochanter and Ward's triangle. Osteoporos Int 12:438−444.
17. Simmons A, Simpson DE, O'Doherty MJ, Barrington S, Coakley AJ. 1997 The effects of standardization and reference values on patient classification for spine and femur dual-energy X-ray absorptiometry. Osteoporos Int 7:200−206.
18. Mazess RB, Barden H. 1999 Bone density of the spine and femur in adult white females. Calcif Tissue Int 65:91−99.
19. Hologic, Data on file.
20. Looker AC, Wahner HW, Dunn WL, et al. 1998 Updated data on proximal femur bone mineral levels of US adults. Osteoporos Int 8:468−489.
21. Pocock NA, Sambrook PN, Nguyen T, Kelly P, Freund J, Eisman JA. 1992 Assessment of spinal and femoral bone density by dual X-ray absorptiometry: comparison of Lunar and Hologic instruments. J Bone Miner Res 7:1081−1084.
22. Laskey MA, Crisp AJ, Cole TJ, Compston JA. 1992 Comparison of the effect of different reference data on Lunar DPX and Hologic QDR-1000 dual-energy X-ray absorptiometers. Br J Radiol 65:1124−1129.
23. Faulkner KG, Roberts LA, McClung MR. 1996 Discrepancies in normative data between Lunar and Hologic DXA systems. Osteoporos Int 6:432−436.
24. Pearson J, Dequeker J, Reeve J, et al. 1995 Dual x-ray absorptiometry of the proximal femur: normal European values standardized with the European spine Phantom. J Bone Miner Res 10:315−324.
25. Ahmed AIH, Blake GM, Rymer JM, Fogelman I. 1997 Screening for osteopenia and osteoporosis: do the accepted normal ranges lead to overdiagnosis? Osteoporos Int 7:432−438.
26. Gürlek A, Bayraktar M, Ariyüruk M. 2000 Inappropriate reference range for peak bone mineral density in dual-energy X-ray absorptiometry: implications for the interpretation of T-scores. Osteoporos Int 11:809−813.
27. Bouyoucef SE, Cullum ID, Ell PJ. 1996 Cross-calibration of fan-beam X-ray densitometer with a pencil-beam system. Br J Radiol 69:522−531.
28. Mazess RB, Barden HS. 2000 Evaluation of differences between fan-beam and pencil-beam densitometers. Calcif Tissue Int 67: 291−296.
29. Orwoll E, Ettinger M, Weiss S, et al. 2000 Alendronate for the treatment of osteoporosis in men. N Engl J Med 343:604−610.

30. Reid DM, Adami S, Devogelaer JP, Chines AA. 2001 Risedronate increases bone mineral density and reduces vertebral fracture risk within one year in men on corticosteroid therapy. Calcif Tissue Int 69:242−247.
31. Kaufman JM, Orwoll E, Goemaere S, et al. 2005 Teriparatide effects on vertebral fractures and bone mineral density in men with osteoporosis: treatment and discontinuation of therapy. Osteoporos Int 16:510−516.
32. Kanis J, Black D, Cooper C, et al. 2002 A new approach to the development of assessment guidelines of osteoporosis. Osteoporos Int 13:527−536.
33. Eddy D, Johnston CC, Cummings SR, et al. 1998 Osteoporosis: review of the evidence for prevention, diagnosis and treatment and cost-effectiveness analysis. Osteoporos Int 8(Suppl 4):1−88.

Appendix A. The Executive Board of the BBC

The executive board of the BBC consists of the following investigators: Jean-Jacques Body, MD, PhD (Université Libre de Bruxelles), Steven Boonen, MD, PhD (Katholieke Universiteit Leuven), Yves Boutsen, MD, (Université catholique de Louvain), Jean-Pierre Devogelaer, MD, (Univedrsité catholique de Louvain), Stefan Goemaere (MD) (Universiteit Gent), Jean-Marc Kaufman, MD, PhD (Universiteit Gent), Jean-Yves Reginster, MD, PhD (Université d'Etat de Liège), and Serge Rosenberg, MD, PhD (Université Libre de Bruxelles).

Appendix B. Network on Male Osteoporosis in Europe

The NEMO is a Thematic Network supported by the European Commission under contract QLK6-CT-2002-00491. Participants in NEMO are S. Boonen (Leuven University, Belgium), J. Blanch (University of Barcelona, Spain), D. Chappard (Université d'Angers, France), J. Compston (University of Cambridge, UK), C. Cooper (MRC, Southampton, UK), J.P. Devogelaer (St. Luc University, Belgium), M.C. de Vernejoul (INSERM Paris, France), C. Glüer (University of Kiel, Germany), S. Goemaere (Ghent University Hospital, Belgium), J.M. Kaufman (NEMO Coordinator), O. Johnell[†] (Lunds University, Sweden), J. Kanis (University of Sheffield, UK), J.M. Kaufman (NEMO Coordinator, Ghent University, Belgium), P. Lips (Free University of Amsterdam, The Netherlands), D. Navid (International Osteoporosis Foundation, Lyon, France), R. Nuti (University of Siena, Italy), S. Ortolani (Instituto Auxologico Italiano, Italy), P. Delmas and P. Szulc (INSERM Lyon, France), J. Reeve (Addenbrooke's Hospital Cambridge, UK), R. Rizzoli (CHU Cantonal Geneva, Switzerland), J. Stepan (Charles University Prague, Czech Republic), and A. Uitterlinden (Erasmus University Rotterdam, The Netherlands).

Appendix C. Formulas Used to Standardize the BMD Values

Lumbar spine sBMD (mg/cm^2)

Genant et al. *(13)*

Hologic: $\text{LS BMD} = (1.0755 \times \text{BMD}_\text{H}) \times 1000$

Lunar: $\text{LS BMD} = (0.9522 \times \text{BMD}_\text{L}) \times 1000$

Hui et al. *(14)*

Hologic: $\text{LS BMD} = [1.0550(\text{BMD}_\text{H} - 0.972) + 1.0436] \times 1000$

Lunar: $\text{LS BMD} = [0.9683(\text{BMD}_\text{L} - 1.100) + 1.0436] \times 1000$

Total hip sBMD (mg/cm^2)

Hanson et al *(15)*

Hologic: $\text{TH sBMD} = 1008 \times \text{BMD}_\text{H} + 6$

Lunar: $\text{TH sBMD} = 979 \times \text{BMD}_\text{L} - 31$

Lu et al. *(16)*

Hologic: $\text{TH sBMD} = [0.006 + (1.008 \times \text{BMD}_\text{H})] \times 1000$

Lunar: $\text{TH sBMD} = [-0.031 + (0.979 \times \text{BMD}_\text{L})] \times 1000$

Femoral neck sBMD (mg/cm^2)

Lu et al. *(16)*

Hologic: $\text{FN sBMD} = [0.019 + (1.087 \times \text{BMD}_\text{H})] \times 1000$

Lunar: $\text{FN sBMD} = [-0.023 + (0.939 \times \text{BMD}_\text{L})] \times 1000$

Simmons et al. *(17)*

Hologic: $\text{FN sBMD} = [(1.031 \times \text{BMD}_\text{H}) + 0.058] \times 1000$

Lunar: $\text{FN sBMD} = [(0.961 \times \text{BMD}_\text{L}) - 0.037] \times 1000$