Bone mineral density assessed by quantitative ultrasound and dual energy X-ray absorptiometry

Normative data in Malmö, Sweden

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We measured bone mineral density (BMD) in 128 men and 143 women, aged 22–90, by dual energy X-ray absorptiometry (DEXA) and quantitative ultrasound (QUS). We found reduced bone mineral density in relation to age as measured both by DEXA and QUS. There was a correlation between 0.28 and 0.52 in men and between 0.53 and 0.77 in women when comparing DEXA and QUS measurements. When including only persons with low bone mass, the correlation was less.

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During recent decades, efforts have been made to estimate the skeleton by non-invasive bone mass measurement to detect osteoporosis and monitor response to therapy. Since bone mass is related to bone strength (Riggs et al. 1981, Cummings 1989), it is important to identify persons with low bone mineral density (BMD) in the prevention of subsequent osteoporosis fractures, which rarely occur above certain levels of BMD (Riggs et al. 1981, Grubb et al. 1984, Ross et al. 1987). Only 60% of the increase in hip fracture incidence can be accounted for by the increasing life expectancy of the population (Cummings 1989, Gullberg et al. 1993). Other factors, such as the age-adjusted decrease in BMD or a structural change in bone architecture, could account for some of the increase (Karlsson et al. 1993).

Various radiological techniques are available for non-invasive assessment of bone mineral mass—single photon absorptiometry (SPA), dual photon absorptiometry (DPA), single energy X-ray absorptiometry (SXA) and dual energy X-ray absorptiometry (DEXA) are the most frequently used (Mazess and Wahner 1988). These methods are reproducible (Genant et al. 1996) and are documented for the prediction of fractures due to osteoporosis (Cummings et al. 1993, Marshall et al. 1996). The above-mentioned methods measure BMD but not structural changes such as trabecular numbers, connectivity and orientation (Genant et al. 1996).

Today, quantitative ultrasound (QUS) has gained popularity for assessment of skeletal status (Genant et al. 1996). The method measures speed of sound (SOS), defined as the ratio of transit time and body part width or length and is expressed as meters per second (m/s). Another variable is attenuation (broadband ultrasound attenuation, BUA)—energy removed from the wave by absorption and scattering (dB/MHz). Preliminary data indicate that not only BMD but also microstructural architecture such as trabecular separation affect the measurement (McCarthy et al. 1990, Glüer et al. 1994). The preliminary results also show a good diagnostic sensitivity for fracture discrimination (Genant et al. 1996). The attractiveness of QUS lies in low cost, portability, simplicity, freedom from ionizating radiation and possible estimation of microarchitectural changes.

We collected normative bone mass data, evaluated by QUS and DEXA, in men and women 22–90 years of age, in the city of Malmö, Sweden and also correlated the DEXA and QUS measurements in all persons, including those with low bone mass.

Probands and methods

BMD was measured in 128 men (age 23–90) and 143 women (age 22–90) during 1994. Half of the probands were randomly selected from the city files and half were volunteers, mostly hospital employees. 50% of those invited from the city files attended. Only caucasians were included.

All probands were measured by DEXA, using the Lunar DPX-L® equipment. The areal bone mineral density—BMD (g/cm^2) of the total body, the left hip (neck, Ward's triangle and trochanter region) and the lumbar spine (L2–L4)—was calculated. In 118 men

Table 1. Bone mineral data in men measured by DEXA and QUS. Mean (SD)

Age group	20–29	30–39	40–49	50–59	60–69	70–79	>80
n	11	21	13	26	22	16	19
Age	26.5 (1.9)	35.0 (3.5)	45.2 (2.8)	54.7 (2.9)	64.4 (3.1)	75.8 (3.7)	83.8 (3.4)
Total body BMD g/cm^2	1.21 (0.07)	1.26 (0.08)	1.19 (0.09)	1.19 (0.07)	1.18 (0.06)	1.15 (0.10)	1.12 (0.11)
Hip BMD neck g/cm^2	1.03 (0.14)	1.07 (0.15)	0.92 (0.10)	0.93 (0.13)	0.91 (0.10)	0.83 (0.15)	0.85 (0.17)
Hip BMD Ward g/cm^2	1.00 (0.18)	0.99 (0.19)	0.82 (0.15)	0.81 (0.11)	0.77 (0.13)	0.69 (0.17)	0.72 (0.17)
Hip BMD trochanter g/cm^2	0.89 (0.14)	0.98 (0.14)	0.90 (0.10)	0.92 (0.14)	0.93 (0.12)	0.91 (0.16)	0.92 (0.18)
Spine BMD L2-L4 g/cm^2	1.27 (0.11)	1.29 (0.17)	1.19 (0.16)	1.15 (0.15)	1.18 (0.22)	1.21 (0.26)	1.24 (0.21)
SOS m/s	1562 (29)	1579 (43)	1538 (37)	1542 (41)	1532 (29)	1527 (32)	1510 (26)
BUA dB/MHz	120 (8.4)	125 (9.7)	121 (7.9)	122 (13.6)	119 (9.9)	117 (12)	113 (9.2)

Table 2. Bone mineral data in women measured by DEXA and QUS. Mean (SD)

Age group	20–29	30–39	40–49	50–59	60–69	70–79	>80
n	15	21	20	25	21	21	20
Age	25.9 (2.3)	34.5 (2.7)	45.0 (3.1)	54.0 (2.7)	65.0 (3.5)	76.1 (3.2)	84.1 (3.1)
Total body BMD g/cm^2	1.15 (0.09)	1.16 (0.06)	1.12 (0.08)	1.13 (0.07)	1.00 (0.08)	1.00 (0.10)	0.90 (0.08)
Hip BMD neck g/cm^2	0.99 (0.20)	0.99 (0.13)	0.92 (0.14)	0.93 (0.14)	0.77 (0.18)	0.75 (0.15)	0.68 (0.09)
Hip BMD Ward g/cm^2	0.97 (0.25)	0.90 (0.16)	0.83 (0.16)	0.82 (0.17)	0.64 (0.19)	0.61 (0.14)	0.53 (0.11)
Hip BMD trochanter g/cm^2	0.86 (0.17)	0.83 (0.09)	0.80 (0.12)	0.84 (0.12)	0.70 (0.20)	0.76 (0.17)	0.65 (0.11)
Spine BMD L2-L4 g/cm^2	1.20 (0.12)	1.27 (0.12)	1.19 (0.11)	1.16 (0.15)	0.93 (0.13)	1.01 (0.20)	0.92 (0.23)
SOS m/s	1566 (30)	1559 (22)	1532 (26)	1538 (35)	1500 (19)	1509 (38)	1470 (18)
BUA dB/MHz	118 (13)	119 (7.2)	114 (8.7)	114 (11)	106 (7.9)	105 (13)	92 (11)

and 125 women QUS was also performed in both os calcis with Achilles® ultrasound equipment (Lunar-Achilles®). The standard measuring areas were defined by the same laboratory technicians who excluded measurements with technical errors. In addition, all measurements were examined by two of the authors independently, excluding not usable measurements that could not be used, such as too small measuring areas, blurred pictures or metallic implants.

The precision of our DEXA equipment, as assessed by double measurements in healthy persons after repositioning, is for the total body 0.4%, for hip (neck region) 1.6% and for the lumbar spine (L2–L4) 0.5%. The precision of the ultrasound equipment measuring the os calcis is 1.5%.

Multiple regression analysis was used for the data.

Results

BMD, as estimated by QUS and DEXA measurements in both men and women, divided into 10-year age classes, is presented in Tables 1 and 2. The correlations between QUS and DEXA measurements in both men and women are shown in Tables 3 and 4. The correlations between QUS and DEXA measurements in the lower quartile, as regards BMD total body, are shown in Tables 5 and 6.

11 men and 33 women were below 2.5 SD, as compared with BMD total body in young subjects of the same gender—osteoporotic when using the definition proposed by the World Health Organization (WHO). In this group, 8 men and 29 women also had QUS performed. Of the 8 men, 3 were also osteoporotic as judged by SOS (<2.5 SD, compared with young subjects of the same gender) and 2, as judged by BUA. Of the 29 women defined as osteoporotic by the DEXA measurement and where QUS was performed as well, 27 were also defined as osteoporotic by SOS and 20 by BUA.

The corresponding figures, using DEXA lumbar spine or DEXA hip as a reference for diagnosing osteoporosis, are presented in Table 7.

Discussion

Our study indicates a low correlation between QUS, both speed of sound and broadband attenuation, as compared to DEXA measurements. Since DEXA is supposed to be the "golden standard" when measuring bone mass, QUS seems not to be optimal as a diagnostic tool for absolute bone mass measurements. Other studies have shown a correlation in vivo between QUS measured in the heel and DEXA—0.33–0.83 for the lumbar spine and 0.33–0.87 for the femoral neck (Baran et al. 1991, Faulkner et al. 1994). These correlations were significant, indicating that about 50% of the variation in QUS depends on factors other than absolute BMD. Whether the unexplained

Table 3. Correlations (r) between bone mass measurements, using DEXA and QUS, in men

	Total body BMD g/cm^2	Hip BMD neck g/cm^2	Hip BMD Ward g/cm^2	Hip BMD trochanter g/cm^2	Spine BMD L2–L4 g/cm^2	SOS m/s	BUA dB/MHz
Total body BMD g/cm^2	1.00						
Hip BMD neck g/cm^2	0.82	1.00					
Hip BMD Ward g/cm^2	0.81	0.93	1.00				
Hip BMD trochanter g/cm^2	0.71	0.75	0.68	1.00			
Spine BMD L2–L4 g/cm^2	0.64	0.53	0.55	0.58	1.00		
SOS m/s	0.52	0.50	0.50	0.38	0.31	1.00	
BUA dB/MHz	0.41	0.36	0.30	0.28	0.30	0.79	1.00

Table 4. Correlations (r) between bone mass measurements, using DEXA and QUS, in women

	Total body BMD g/cm^2	Hip BMD neck g/cm^2	Hip BMD Ward g/cm^2	Hip BMD trochanter g/cm^2	Spine BMD L2–L4 g/cm^2	SOS m/s	BUA dB/MHz
Total body BMD g/cm^2	1.00						
Hip BMD neck g/cm^2	0.85	1.00					
Hip BMD Ward g/cm^2	0.84	0.96	1.00				
Hip BMD trochanter g/cm^2	0.70	0.81	0.78	1.00			
Spine BMD L2–L4 g/cm^2	0.81	0.75	0.76	0.60	1.00		
SOS m/s	0.77	0.74	0.76	0.54	0.62	1.00	
BUA dB/MHz	0.75	0.71	0.68	0.53	0.59	0.78	1.00

Table 5. Correlations (r) between DEXA and QUS in men, including only those in the lower quartile of total body BMD

	Total body BMD g/cm^2	Hip BMD neck g/cm^2	Hip BMD Ward g/cm^2	Hip BMD trochanter g/cm^2	Spine BMD L2–L4 g/cm^2	SOS m/s	BUA dB/MHz
Total body BMD g/cm^2	1.00						
Hip BMD neck g/cm^2	0.54	1.00					
Hip BMD Ward g/cm^2	0.53	0.80	1.00				
Hip BMD trochanter g/cm^2	0.48	0.61	0.44	1.00			
Spine BMD L2–L4 g/cm^2	0.27	0.18	0.17	0.35	1.00		
SOS m/s	0.39	0.00	0.10	–0.09	0.07	1.00	
BUA dB/MHz	0.28	–0.09	-0.01	0.08	0.21	0.77	1.00

Table 6. Correlations (r) between DEXA and QUS in women, including only those in the lower quartile of total body BMD

	Total body BMD g/cm^2	Hip BMD neck g/cm^2	Hip BMD Ward g/cm^2	Hip BMD trochanter g/cm^2	Spine BMD L2–L4 g/cm^2	SOS m/s	BUA dB/MHz
Total body BMD g/cm^2	1.00						
Hip BMD neck g/cm^2	0.42	1.00					
Hip BMD Ward g/cm^2	0.32	0.91	1.00				
Hip BMD trochanter g/cm^2	0.11	0.63	0.54	1.00			
Spine BMD L2-L4 g/cm^2	0.69	0.39	0.35	0.16	1.00		
SOS m/s	0.32	0.33	0.25	0.10	0.27	1.00	
BUA dB/MHz	0.55	0.33	0.32	–0.01	0.47	0.73	1.00

50% are related to bone strength or other factors unrelated to osteoporosis has yet to be determined. The low correlation with DEXA measurements does not exclude QUS as a predictor of future osteoporosis fractures, since not only BMD but the microarchitectural structure also influences the risk of fragility fractures (McCarthy et al. 1990, Glüer et al. 1992).

Some studies indicate that ultrasound transmission

Table 7. Persons diagnosed as osteoporotic by DEXA measurements and where QUS was also performed

	Men		Women	
Osteoporotic as defined by DEXA measurement of	Osteoporotic as defined by measurement of BUA	Osteoporotic as defined by measurement of SOS	Osteoporotic as defined by measurement of BUA	Osteoporotic as defined by measurement of SOS
Total body	2/8	3/8	20/29	27/29
Femoral neck	1/10	3/10	12/21	17/21
Lumbar spine	1/9	3/9	15/32	21/32

velocity is related directly not only to BMD but also to the elasticity of human and bovine bone (Abendschein and Hyatt 1970, Ashman et al. 1984). Other studies with trabecular bone samples show that velocity correlates well with ultimate strength (r = 0.71–0.75) (Ashman et al. 1988, Turner and Eich 1991). These results strongly suggest a relationship between bone structure and strength beyond that which can be explained by BMD. This is emphasized even more by studies indicating that QUS can predict vertebral fractures with the same effectiveness as conventional BMD measurements of the spine, hip and forearm (Heaney et al. 1989,1995).

When correlating findings in subjects with low bone mass (<25% percentile of BMD total body), the correlations between DEXA and QUS measurements were less than when all persons were included. This indicates that in those who develop fragility fractures, the difference between absolute bone mass measurements and changed architectural structure may be even greater. It seems that in osteoporotic persons the two methods present information about different aspects of bone. This is in line with earlier studies indicating that both DEXA and QUS measurements independently predict fragility fractures (Schott et al. 1995, Turner et al. 1995).

In men defined as osteoporotic by DEXA measurements, only one third were also classified as osteoporotic by the use of ultrasound SOS and one fourth by the use of ultrasound BUA, applying the WHO definition (<2.5 SD below young adults). In women, the agreement was 93% using SOS and 69% using BUA, again indicating that QUS may not measure the same modality of the bone as the DEXA measurement.

The number of subjects classified as osteoporotic differs, depending on the method or region used for evaluation of bone mass. When using the definition of osteoporosis suggested by WHO, 9–29% of all the women and 1–10% of all the men measured in our study were below 2.5 standard deviations as compared to young persons of the same sex by DEXA measurements in the different skeletal regions. When using ultrasound, one third of all women using SOS and one fourth using BUA were classified as osteoporotic. Corresponding figures for men were 11% and 4%, respectively. It seems important to define both the region and the method when describing the rate of individuals with osteoporosis in a normative population.

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