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Low grip strength is associated with bone mineral density and vertebral fracture in women

W. G. Dixon, M. Lunt, S. R. Pye, J. Reeve[1], D. Felsenberg[2], A. J. Silman and T. W. O'Neill, on behalf of the European Prospective Osteoporosis Study Group[†]

Objectives. **Grip strength has been reported to be associated with bone mass locally at the forearm and also at distant skeletal sites, including the spine and hip. Less is known about the association between low grip strength and risk of vertebral fracture. The aim of this study was to examine the association between low grip strength, bone mineral density at the hip and spine, and vertebral fracture in middle-aged and elderly European men and women.**

Methods. **Men and women aged 50 yr and over were recruited for participation in a screening survey of vertebral osteoporosis across Europe. Subjects who agreed to take part had an interviewer-administered questionnaire and lateral spinal radiographs performed. Subjects were assessed also for grip strength using a handgrip dynamometer (range 0–300 mmHg). A subsample of those recruited had bone mineral density measurements performed at the spine and femoral neck. Subjects had repeat lateral spine radiographs performed a mean of 3.8 yr following the baseline survey. Linear regression analysis was used to determine the association between low grip strength and bone mineral density at the hip and spine. Logistic regression was used to determine the association between grip strength and both prevalent and incident vertebral fracture.**

Results. **One thousand two hundred and sixty-five men and 1380 women with data concerning grip strength and bone mineral density were included in the analysis. In women, after age adjustment, compared with those with 'normal' grip, those with 'impaired' (231–299 mmHg) and low grip (<231 mmHg) had significantly lower bone mass at the spine and femoral neck. In men, those with low grip strength had a lower BMD at the spine and hip than those in the normal group. However, because of the small numbers with submaximal grip strength, the confidence intervals around all estimates included zero. Adjustment for body size and levels of physical activity had little effect on the results. In addition, among women, after adjustment for age, body mass index and physical activity levels, compared with those with normal grip, those with low grip strength had an increased risk of developing incident vertebral fracture (odds ratio = 2.67; 95% confidence interval 1.13, 6.30). Further adjustment for spine bone density had little influence on the association (odds ratio = 2.60).**

Conclusions. **In women, low grip strength is associated with low bone mineral density at both the spine and hip and an increased risk of incident vertebral fracture. These associations cannot be explained by differences in body size or lifestyle.**

KEY WORDS: Grip strength, Bone mineral density, Vertebral fracture, Physical activity, Body size.

Skeletal muscle contraction forces generate large reaction forces during normal activity and such forces are thought to have a trophic or adaptive effect on bone mass locally. An example of this adaptation is an increase in humeral bone mass in tennis players [1, 2]. Most observational studies among non-athletes have reported a positive association between hand grip strength and bone mass locally—at the wrist or forearm [3–10]. Among women, most studies also suggest a positive relationship with bone mass at other sites including the hip and/or spine [4, 6, 11–15]. There are fewer studies in men. Several have reported no statistically significant association between grip strength and bone mineral density (BMD) at the hip or upper limb BMD [15–18], though others have reported a positive association with total body bone mineral [19]. In addition, there are few data concerning the relationship with vertebral fracture and the evidence from these studies is conflicting [20, 21]. To our knowledge there are no data concerning the influence of a low grip strength on the occurrence of incident radiographic vertebral fractures. One study has shown an association between grip strength and incident osteoporotic fractures (including vertebral fractures), though the association with vertebral fractures alone was not examined [22].

Our aim was to determine the extent of any association between low handgrip strength and both bone density at the hip and spine, and vertebral fractures in men and women.

ARC Epidemiology Unit, Stopford Building, University of Manchester, Manchester, [1]University Department of Medicine, Strangeways Research Laboratory, Cambridge, UK and [2]Department of Radiology and Nuclear Medicine, Free University, Berlin, Germany.

[†]Members of the group are listed in Appendix 1, available as supplementary data at *Rheumatology* Online.

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Correspondence to: T. W. O'Neill, ARC Epidemiology Unit, Stopford Building, University of Manchester, Manchester M13 9PT, UK.
E-mail: terry@fs1.ser.man.ac.uk

We looked also at the influence of body size and physical activity variables on these associations.

Methods

Subjects

Subjects were recruited for participation in a population screening survey of osteoporosis: the European Prospective Osteoporosis Study (EPOS). In this survey, men and women aged 50 yr and over were recruited from population registers across Europe [23]. Those who agreed to take part had an interviewer-administered lifestyle questionnaire. In the questionnaire, subjects were asked to 'broadly indicate the most strenuous level of activity carried out daily during each of the following periods of your life' for the three age periods 15–25, 25–50 and over 50 yr (response set: light/moderate/heavy/very heavy) [24]. A glossary was provided giving examples of activities and relating them to an activity level. Current activity levels were assessed by response to the question 'How much time do you typically spend walking or on a bicycle out of doors each day?' (response set: none/some but less than half an hour/half to one hour/more than one hour). Height and weight were measured in all subjects. Each subject gave informed consent to their participation in the manner required by their centre's research ethics committee.

Assessment of grip strength

Grip strength was measured using an Accoson handgrip 'Limpet' dynamometer. The subject's arm was positioned with the elbow flexed and the forearm parallel to the floor. The subject squeezed the inflated cuff between the ball of the hand and the fingers without using the thumb. The maximum value was noted for each squeeze and the highest of three attempts was recorded. The analogue scale ranged from 0–300 mmHg. It was possible to go beyond the upper range; if this was the case a value of 300 mmHg was recorded.

Bone mineral density assessment

Hip and spine BMD was assessed in a subsample of participating centres. In these centres, random samples of between 20 and 100% of subjects were invited for bone densitometry. Overall, 52% of subjects at the 10 centres who had data about grip strength and BMD measurements available had both hip and spine BMD measured. Further details about assessment of bone densitometry are described elsewhere [25]. The densitometers in each centre were pencil beam machines made by Lunar, Hologic or Norland and were cross-calibrated using the European Spine Phantom [26, 28]. At least five measurements of the phantom were made on each machine and a two-parameter empirically fitted exponential calibration curve was used to convert measured density values into standardized values, as described by Pearson *et al*. [27].

Radiological assessment

All subjects had lateral thoracolumbar spine radiographs performed using a standard protocol. Subjects had repeat spinal radiographs performed a mean of 3.8 yr after the baseline survey. The radiographs were forwarded to the radiology coordinating centre in Berlin for evaluation. Both prevalent and incident vertebral fractures were defined according to standard morphometric criteria. For prevalent fractures the McCloskey–Kanis criteria were used [29]. Incident fractures were defined if there was evidence of height reduction of 20% or more in any of the three vertebral heights (anterior, middle or posterior) between films and, in the second film, if a vertebra satisfied criteria for a prevalent fracture [30]. The study radiologist also made a clinical (qualitative) assessment about whether an incident vertebral fracture was present.

Statistical analysis

Grip strength was examined as a categorical variable because of the ceiling effect of the dynamometer. Those subjects who obtained a maximal grip strength score of 300 mmHg formed one group, which was labelled 'normal'. Excluding those with maximal grip strength, the remainder were subdivided at the median value of 230 mmHg (which was the same value for men and women), the resulting two groups being labelled 'impaired' (231–299 mmHg) and low (<231 mmHg). BMI was calculated by dividing weight by height squared (kg/m^2). A lifetime activity score was calculated by summating the scores for the physical activity questions from each of the three age periods. Current physical activity was dichotomised (walking or cycling daily >1 h/<1 h).

Linear regression was used to investigate the association between low grip strength and bone mineral density with adjustments made for age. The analysis was repeated after adjusting for body mass index and both the lifetime activity score and current physical activity levels. Logistic regression was used to look at the association between low grip and the occurrence of both prevalent and incident vertebral fracture. Analyses were undertaken separately in men and women. Statistical analysis was performed using Stata [31].

Results

Subjects

In total, there were 1265 men, mean age 64.1 (S.D. = 8.5) and 1380 women, mean age 63.6 (S.D. = 8.2), who had both grip strength and hip/spine BMD measurements available. Of these 2645 subjects, 2553 had baseline lateral spine X-rays and 1389 had baseline and follow-up films.

Baseline characteristics

The baseline characteristics of the subjects are detailed in Table 1. BMD scores were higher for men than women at the femoral neck (0.827 *vs* 0.726 g/cm^2), the trochanter (0.768 *vs* 0.621 g/cm^2), and the spine (1.091 *vs* 0.935 g/cm^2). Men undertook higher levels of physical activity than women. A greater proportion of men were recorded as having normal grip strength (89 *vs* 37%). In all, 135 (11.0%) of men and 187 (14.1%) of women had evidence of a prevalent vertebral fracture. Amongst those subjects with follow-up radiographs, 11 (1.7%) men and 34 (4.7%) women had evidence of an incident vertebral fracture (either morphometric [40] or qualitative [38]).

Grip strength and BMD

The associations between grip strength category and BMD at the spine and femoral neck are shown in Table 2. Among women, compared with those with normal grip, those with impaired and low grip had significantly lower bone mass at the spine and femoral neck. At the femoral trochanter, bone mass was lower in those with impaired and low grip, though for the former the confidence limits included unity. At all skeletal sites there was also a statistically significant trend towards lower bone mass with lower grip strength ($P < 0.05$). In men, those with both impaired and low grip strength had lower BMD than those in the normal group but, because of the lower numbers of men with submaximal grip strength, the confidence intervals around all the estimates included zero. The absolute difference in bone mass between the three grip strength groups, however, was similar in men and women. Adjustment for body size and levels of physical activity had little effect on the results (Table 2).

Grip strength and vertebral fracture

In both men and women, a low grip strength was associated with an increased risk of prevalent vertebral fracture, though none of these associations was statistically significant (Table 3). Among women, however, after adjusting for age, BMI and physical activity levels, there was an increased risk of incident vertebral fracture among those with a low grip [odds ratio (OR) = 2.67]. Further adjustment for spine BMD did not attenuate risk (OR = 2.60) (Table 3). Among men with a normal grip strength, only nine (1.5%) had evidence of incident vertebral fracture. The corresponding figures for those with impaired and low grip were 1 (2.4%) and 1 (3.5%), respectively. Therefore, the numbers with incident vertebral fracture in the non-normal grip strength groups were too small to permit further analysis.

TABLE 1. Subject characteristics

	Mean (S.D.)	
	Men ($n = 1265$)	Women ($n = 1380$)
Age (yr)	64.1 (8.5)	63.6 (8.2)
BMI (kg/m^2)	27.0 (3.3)	27.4 (4.6)
BMD femoral neck (g/cm^2)	0.827 (0.144)	0.726 (0.140)
BMD trochanter (g/cm^2)	0.768 (0.142)	0.621 (0.125)
BMD spine (g/cm^2)	1.091 (0.238)	0.935 (0.219)
Lifetime activity score[a]	6.7 (2.3)	5.9 (2.0)
	n (%)	
Grip strength		
Normal (≥300 mmHg)	1119 (88.5)	516 (37.4)
Impaired (231–299 mmHg)	80 (6.3)	441 (32.0)
Low (0–230 mmHg)	66 (5.2)	423 (30.6)
Walking/cycling (per day)		
Up to 1 h	506 (40.0)	813 (59.0)
>1 h	758 (60.0)	565 (41.0)

[a]Range 3–12 (sum of response sets 1–4 for the three age periods 15–25, 25–50 and ≥50 yr).

Discussion

In this population-based study we have shown that low grip strength is associated with reduced BMD at both the spine and femoral neck in women. The association could not be explained by differences in body size or levels of physical activity. Among women, low grip strength was also associated with an increased risk of incident vertebral fracture.

There are a number of methodological limitations to be considered in interpreting the results. The response rate for participation in the screening survey in those centres that contributed data to the study was approximately 55% [32]. It is possible that those who declined to participate may have differed with respect to grip strength from those who took part. However, any possible selection factors are unlikely to have influenced the main findings, which are based on an internal comparison of those who participated.

The handgrip dynamometer used in the study had a low ceiling, particularly in men, fully 89% of whom attained the maximum recordable value. Thus, in men, because of the small numbers in the impaired and low grip-strength groups, the confidence intervals were relatively wide. Assessment of grip strength was undertaken without knowledge of the bone density data. Any errors in recording are thus likely to be random and, if anything, would tend to reduce the chance of finding significant biological associations.

In our study the questionnaire instrument concerning current and historical physical activity was also relatively crude. It is possible that the lack of effect of physical activity on the association between bone mass and grip strength was because of the failure of the question to capture accurately the typical recreational, leisure and occupational activities of the subjects. Further studies incorporating more detailed information about the type, frequency and intensity of physical activities undertaken would be required to further explore this.

Our results are consistent with the majority of previous studies among women showing an association between grip strength and bone mass at the spine [4, 6, 11, 13, 14] and the hip [4, 6, 13–15]. Zimmerman *et al.* reported no association between bone mass

TABLE 2. Grip strength and bone mineral density at the spine and hip in men and women

BMD site + grip strength	Men (β coeff. (95% CI)) Age-adjusted	Men Multivariate[a]	Women [β coeff. (95% CI)] Age-adjusted	Women Multivariate[a]
Femoral neck				
Normal	Referent	Referent	Referent[b]	Referent[b]
Impaired	−0.007 (−0.040, 0.025)	−0.002 (−0.033, 0.029)	−0.022 (−0.039, −0.005)	−0.020 (−0.036, −0.004)
Low	−0.023 (−0.058, 0.013)	−0.032 (−0.066, 0.003)	−0.019 (−0.037, −0.002)	−0.023 (−0.040, −0.006)
Trochanter				
Normal	Referent	Referent	Referent[b]	Referent[b]
Impaired	−0.012 (−0.045, 0.021)	−0.006 (−0.037, 0.026)	−0.013 (−0.028, 0.002)	−0.012 (−0.026, 0.002)
Low	−0.018 (−0.054, 0.017)	−0.030 (−0.065, 0.004)	−0.018 (−0.034, −0.002)	−0.023 (−0.038, −0.008)
Spine				
Normal	Referent	Referent	Referent[b]	Referent[b]
Impaired	0.018 (−0.037, 0.073)	0.027 (−0.027, 0.081)	−0.051 (−0.079, −0.024)	−0.055 (−0.082, −0.028)
Low	−0.024 (−0.084, 0.035)	−0.043 (−0.103, 0.016)	−0.037 (−0.066, −0.008)	−0.046 (−0.074, −0.017)

[a]Adjustments made for age, BMI, lifetime activity score and current activity.
[b]Test for trend: $P < 0.05$.
β coeff. = β coefficient; CI = confidence interval.

TABLE 3. Grip strength and vertebral fracture in men and women

	Men (OR (95% CI))		Women (OR (95% CI))	
Fracture type + grip strength	Age-adjusted	Multivariate[a]	Age-adjusted	Multivariate[a]
Prevalent vertebral fracture				
Normal	Referent	Referent	Referent	Referent
Impaired	0.87 (0.42, 1.82)	0.85 (0.41, 1.79)	1.50 (0.99, 2.27)	1.47 (0.96, 2.24)
Low	1.82 (0.95, 3.49)	1.79 (0.92, 3.45)	1.34 (0.87, 2.06)	1.32 (0.85, 2.05)
Incident vertebral fracture				
Normal	–	–	Referent	Referent
Impaired	–	–	0.31 (0.08, 1.17)	0.37 (0.10, 1.42)
Low	–	–	2.13 (0.93, 4.88)	2.67 (1.13, 6.30)

In men the number of incident vertebral fractures was too small to permit meaningful analysis.
OR = odds ratio; CI = confidence interval.
[a]Adjustments made for age, BMI, lifetime activity score and current activity.

at the hip and grip strength among a series of postmenopausal women, though the number studied (56) was relatively small [11].

There are relatively few data in men. Our data suggest a reduction in bone mass among those with a low grip strength, the magnitude of the difference from the normal grip group being broadly comparable to that observed in women. Because of the relatively small numbers in both the impaired and low grip groups, however, the study lacked sufficient power to show a statistically significant difference. In other studies, small though non-significant correlations were reported between bone mass at the spine and/or hip; however, the numbers of subjects recruited were small (<40) [4, 15]. In a larger study, Glynn *et al*. reported a small increase in bone mass at the hip in men with higher grip, though as in our study the confidence intervals embraced unity [16]. In a population-based sample of 348 men, Proctor *et al*. reported a significant association between grip strength and total body bone mineral [19].

We observed a small though non-significant increase in risk of prevalent vertebral fracture associated with impaired and low grip strength. This is consistent with a recent study in Beijing [21], but differs from the results of a study in Hong Kong, where those in the lowest quartile of grip had a significantly increased risk of prevalent fracture [20]. To our knowledge there are no published data from population surveys concerning the association between low grip strength and incident vertebral fracture. In our study, among women there was an increased risk of incident fracture among those with low grip strength. Whilst it appears that the impaired grip group among women had a reduced risk of incident vertebral fracture, albeit non-significant, the numbers of incident vertebral fractures in this group was small (3, compared with 10 in the normal group and 21 in the low group), making this apparently contradictory finding less robust. The numbers of men with incident vertebral fracture in this data set were too small to permit analysis of an association with grip strength.

Despite the link with low bone mass, the association between low grip strength and incident vertebral fracture in women could not be explained in our study by BMD, suggesting that factors other than bone mass contribute to fracture risk. Such factors may include bone quality, micro-architecture or bone turnover. These could include targeted strengthening of vertebral bodies to resist habitual compressive forces arising from muscular loading that did not translate into a substantial overall BMD increase. Trauma may play a role, though the majority of vertebral fractures are not explained by falls [33]. Low grip may also be a marker for general frailty with decreased reserves in multiple systems, further contributing to increased fracture risk. Thus, grip strength predicts functional limitation, functional decline and mortality in older people [34–36]. Further studies are required to confirm these findings and to determine the mechanism by which low grip strength influences fracture risk.

In summary, our data suggest that in women low grip strength is a marker of low BMD at both the spine and hip and that the association is not explained by differences in either body size or level of physical activity. Low grip strength in women is associated with an increased risk of incident vertebral fracture.

Rheumatology	Key messages
	• In women, low grip strength is a marker of low bone mineral density. • In women, low grip strength is associated with an increased risk of incident vertebral fracture.

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The authors have declared no conflicts of interest.

Supplementary data

Supplementary data are available at *Rheumatology* Online.

References

1. Jones HH, Priest JD, Hayes WC, Tichenor CC, Nagel DA. Humeral hypertrophy in response to exercise. J Bone Joint Surg 1977;59A:204–8.
2. Haapasalo H, Sievanen H, Kannus P, Heinenon A, Oja P, Vuori I. Dimensions and estimated mechanical characteristics of the humerus after long term tennis loading. J Bone Miner Res 1996;11:864–72.
3. Beverly MC, Rider TA, Evans MJ, Smith R. Local bone mineral response to brief exercise that stresses the skeleton. Br Med J 1989;299:233–5.
4. Bevier WC, Wiswell RA, Pyka G, Kozak KC, Newhall KM, Marcus R. Relationship of body composition, muscle strength, and aerobic capacity to bone mineral density in older men and women. J Bone Miner Res 1989;4:421–32.
5. Sinaki M, Wahner HW, Offord KP. Relationship between grip strength and related regional bone mineral content. Arch Phys Med Rehabil 1989;70:823–6.
6. Snow-Harter C, Bouxsein M, Lewis B, Charette S, Weinstein P, Marcus R. Muscle strength as a predictor of bone mineral density in young women. J Bone Miner Res 1990;5:589–95.
7. Bauer DC, Browner WS, Cauley JA *et al.* for The Study of Osteoporotic Fractures Research Group. Factors associated with appendicular bone mass in older women. The Study of Osteoporotic Fractures Research Group. Ann Intern Med 1993;118:657–65.
8. Tsuji S, Tsunoda N, Yata H, Katsukawa F, Onishi S, Yamazaki H. Relation between grip strength and radial bone mineral density in young athletes. Arch Phys Med Rehabil 1995;76:234–8.
9. Osei-Hyiaman D, Ueji M, Toyokawa H, Takahashi H, Kano K. Influence of grip strength on metacarpal bone mineral density in postmenopausal Japanese women: a cross sectional study. Calcif Tiss Int 1999;64:263–6.
10. Di Monaco M, Di Monaco R, Manca M, Cavanna A. Handgrip strength is an independent predictor of distal radius bone mineral density in postmenopausal women. Clin Rheumatol 2000;19:473–6.
11. Zimmerman CL, Smidt GL, Brooks JS, Kinsey WJ, Eekhoff TL. Relationship of extremity muscle torque and bone mineral density in postmenopausal women. Phys Ther 1990;70:302–9.
12. Elliot JR, Hanger HC, Gilchrist NL *et al.* A comparison of elderly patients with proximal femoral fractures and a normal elderly population: a case control study. N Z Med J 1992;105:420–2.
13. Kritz-Silverstein D, Barrett-Connon E. Grip strength and bone mineral density in older women. J Bone Miner Res 1994;9:45–51.
14. Kroger H, Tuppurainen M, Honkanen R, Alhava E, Saarikoski S. Bone mineral density and risk factors for osteoporosis – a population based study of 1600 perimenopausal women. Calcif Tiss Int 1994;55:1–715.
15. Foley KT, Owings TM, Pavol MJ, Grabiner MD. Maximum grip strength is not related to bone mineral density of the proximal femur in older adults. Calcif Tiss Int 1999;64:291–4.
16. Glynn NW, Meilahn EN, Charron M, Anderson SJ, Kuller LH, Cauley JA. Determinants of bone mineral density in older men. J Bone Miner Res 1995;10:1769–77.
17. Van Pottelbergh I, Goemaere S, Nuytinck L, De Paepe A, Kaufman JM. Association of the type I collagen alpha1 Sp1 polymorphism, bone density and upper limb muscle strength in community dwelling elderly men. Osteoporos Int 2001;12:895–901.
18. Taafe DR, Cauley JA, Danielson M *et al.* Race and sex effects on the association between muscle strength, soft tissue, and bone mineral density in healthy elders: the health, aging and body composition study. J Bone Miner Res 2001;16:1343–52.
19. Proctor DN, Melton LJ III, Khosla S, Crowson CS, O'Connor MK, Riggs BL. Relative influence of physical activity, muscle mass and strength on bone density. Osteoporosis Int 2000;11:944–52.
20. Chan HHL, Lau EMC, Woo J, Lin F, Sham A, Leung PC. Dietary calcium intake, physical activity and the risk of vertebral fracture in Chinese. Osteoporos Int 1996;6:228–32.
21. Ling X, Cummings SR, Mingwei Q *et al.* Vertebral fractures in Beijing, China: The Beijing Osteoporosis Project. J Bone Miner Res 2000;15:2019–25.
22. Albrand G, Munoz F, Sornay-Rendu E, DuBoeuf F, Delmas PD. Independent predictors of all osteoporosis-related fractures in healthy postmenopausal women: the OFELY Study. Bone 2003;32: 78–85.
23. O'Neill TW, Felsenberg D, Varlow J, Cooper C, Kanis JA, Silman AJ and the EVOS study group. The prevalence of vertebral deformity in European men and women: the European Vertebral Osteoporosis Study. J Bone Miner Res 1996;11:1010–8.
24. O'Neill TW, Cooper C, Algra D *et al.* Design and development of a questionnaire for use in a multicentre study of vertebral osteoporosis in Europe: the European Vertebral Osteoporosis Study (EVOS). Rheumatol Eur 1995;24:75–81.
25. Lunt M, Felsenberg D, Adams J *et al.* Population-based geographic variations in DXA bone density in Europe: the EVOS study. Osteoporos Int 1997;7:175–89.
26. Dequeker J, Pearson J, Reeve J *et al.* Dual X-ray absorptiometry – cross-calibration and normative reference ranges for the spine: results of a European Community Concerted Action. Bone 1995;17: 247–54.
27. Pearson J, Dequeker J, Henley M *et al.* European semi-anthropomorphic spine phantom for the calibration of bone densitometers: assessment of precision, stability and accuracy. The European Quantitation of Osteoporosis Study Group. Osteoporos Int 1995;5:174–84.
28. Pearson J, Dequeker J, Reeve J *et al.* Dual X-ray absorptiometry of the proximal femur: normal European values standardised with the European Spine Phantom. J Bone Miner Res 1995;10:315–24.
29. McCloskey EV, Spector TD, Eyres KS, Fern ED, O'Rourke N, Vasikaran S, Kanis JA. The assessment of vertebral deformity: a method for use in population studies and clinical trials. Osteoporos Int 1993;3:138–47.
30. Lunt M, Ismail AA, Felsenberg D *et al.* and the EPOS study group. Defining incident vertebral deformities in population studies: a comparison of morphometric criteria. Osteoporos Int 2002;13: 809–15.
31. Stata Corporation. Stata statistical software, release 6.0. College Station (TX): Stata Corporation, 1999.
32. O'Neill TW, Marsden D, Matthis C, Raspe H, Silman AJ and the EVOS study group. Survey response rates: national and regional differences in a European multicentre study of vertebral osteoporosis. J Epidemiol Community Health 1995;49: 87–93.
33. Cooper C, Atkinson EJ, O'Fallon M, Melton LJ III. Incidence of clinically diagnosed vertebral fractures: a population based study in Rochester, Minnesota, 1985–1989. J Bone Miner Res 1992;7:221–7.
34. Laukkanen P, Heikkinen E, Kauppinen M. Muscle strength and mobility as predictors of survival in 75–84 year old people. Age Ageing 1995;24:468–73.
35. Giampaoli S, Ferrucci L, Cecchi F *et al.* Hand grip strength predicts incident disability in non-disabled older men. Age Ageing 1999;28:283–8.
36. Sarkisian CA, Liu H, Gutierrez PR, Seeley DG, Cummings SR, Mangi CM. Modifiable risk factors predict functional decline among older women: a prospectively validated clinical prediction tool. The Study of Osteoporotic Fractures Research Group. J Am Geriatr Soc 2000;48:170–8.