



Vitamin D and muscle strength in patients with previous fractures

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Abstract

Aim To assess the vitamin D status and its association with objective left leg muscle strength measurements in patients with long-bone fracture discharged from a tertiary hospital in Western Australia. The secondary objective was to determine whether tests of balance and functional status are valid predictors of muscle strength and if they correlate with serum 25 hydroxyvitamin D (25OHD) levels.

Methods This was a cross sectional study. Patients who had been discharged from a tertiary hospital following a low impact fracture over a 12-month period were invited to participate. Invitation was through a postal survey audit of osteoporosis risk and treatment and requesting participation in the study. Females over the age of 60 were included. Patients agreeing to participate were invited to attend a research clinic. Patients had demographic data, muscle strength, functional assessments, and biochemical parameters including serum 25OHD assessed.

Results Of the 99 subjects who completed the study, the mean 25OHD level was 52.0 nmol/L. The main univariate associations with 25OHD were cognitive function, functional indices, sun exposure, albumin, and parathyroid hormone (PTH). In a multivariate model, the strongest and most significant association was between muscle strength and 25OHD levels ($r=0.489$, $p<0.001$). Muscle strength was most strongly associated with 25OHD levels >50 nmol/L ($r=0.51$, $p<0.001$).

Conclusion This study demonstrates a significant association between 25OHD levels and left leg muscle strength. This independent association supports the hypothesis that 25OHD deficiency may be responsible for poor muscle strength.

Low trauma fracture is a major health problem for postmenopausal women and to a lesser extent older men. The two major causes of fracture in these groups are osteoporosis and falls. There are established pharmacological treatments for osteoporosis,^{3,4} however treatment of falls is much more difficult.⁵

In the setting of osteoporosis, higher body sway, quadriceps weakness, and conditions linked with increased risk of falling are associated with a significantly increased risk of fractures.^{6,7} Studies have also suggested an association between bone mineral density and muscle strength.⁸

Muscle strength has been shown to decline with age⁹ and has been shown to be associated with the functional status of older people.¹⁰ Frail older people¹¹ and patients with hip fracture¹² are reported to have a high prevalence of vitamin D deficiency due to reduced sunlight exposure, reduced synthesis of vitamin D, low vitamin D dietary intake, poor absorption, and hepato-renal disease.^{11,12}

Receptors for vitamin D metabolites that are functionally responsive to vitamin D have been identified in human skeletal muscle.^{13,14} Vitamin D deficiency and osteomalacia have been shown to be associated with myopathy,^{15,16} and have in some studies^{17,18} been shown to be reversible with vitamin D treatment.

However, other studies looking at vitamin D supplementation in unselected or vitamin D replete patients have shown no benefit with vitamin D supplementation¹⁹ or no association between serum vitamin D level and muscle strength.¹⁶

Fractures caused by falls occur in about 5% of older persons each year.^{1,20} It has been suggested that vitamin D deficient patients are at higher risk of falls due to increased postural sway.^{21,22} In at least one study, supplementation with vitamin D and calcium reduced the risk of falls in recurrent fallers.²⁰ However, evidence for the association between vitamin D levels and muscle strength on objective testing has not been conclusively proven.¹⁶

A possible reason for the inability to show a direct association between vitamin D levels and muscle strength, and the failure to show any improvement with vitamin D supplementation,¹⁹ may be due to poor patient selection. It is postulated that vitamin D replete patients will not benefit from further supplementation.

Hence in this study we looked at a frail, at risk population of patients who had previously been treated for hip or other long-bone fractures following a fall. We assessed muscle strength as the primary measure rather than using an indirect measure like falls.

The main aims of the study were to assess the vitamin D status of this group of patients and to assess whether there is an association between their serum 25 hydroxyvitamin D level and objective muscle strength measurements. The secondary aim was to determine whether tests of balance and functional status are valid predictors of muscle strength and whether they correlate with serum 25 hydroxyvitamin D levels.

Methods

Subjects—Patients were selected from a tertiary hospital database in Western Australia with a primary admission diagnosis of a long-bone fracture as described previously by Inderjeeth et al in *Internal Medicine Journal* (2006).²³

Only subjects who were identified from the case notes as suffering a low impact fracture of the hip, humerus or forearm were invited to participate. Subjects had to be female, aged >60 years, at least 6 months post fracture and be able to walk independently with or without walking aids and participate in muscle strength measurements. 365 patients were identified as suitable from case records over a 12-month period and invited to participate in the study. Patients were mailed an osteoporosis questionnaire and invited to attend a Fracture, Falls and Balance Clinic for assessment of their osteoporosis and offered participation in this study.

Exclusion criteria were male gender, poor cognition (defined as mini mental state examination <20), significant systemic disease limiting their ability to participate, hypercalcaemia, primary hyperparathyroidism, or a long-bone fracture within 6 months to allow for fracture healing and muscle recovery. Patients on vitamin D supplements were allowed in the study. Enrolment occurred throughout the year and was not seasonally based. The protocol was approved by the Sir Charles Gairdner Hospital Ethics Committee. All subjects gave informed consent.

Study design—All patients had demographic data collected and a research nurse and doctor collected information using validated instruments. Instruments selected include the Berg Balance Scale (BBS),²⁴ which was used to determine the subject's balance in a variety of spheres. The subject's daily functional status was assessed using the Frenchay Activity Index (FAI).²⁵

The Modified Bartel Index (MBI)²⁶ was used to assess functional independence in relation to personal care and mobility. The Falls Efficacy Scale (FES)²⁷ was used to assess patient's confidence and fear of falling in carrying out routine tasks. RPH (Royal Perth Hospital) outdoor score^{11,12} was used to measure sunlight exposure [range 0(no exposure) to 7(regular adequate exposure)].

Timed "Up & Go" (TUAG)²⁸ was used as a measure of functional mobility. Cognitive function was assessed using the mini mental state examination (MMSE)²⁹ and mood was assessed using the brief assessment of depression (BASDEC).³⁰

Muscle strength was measured in the left leg using a Keylink Kinitech Dynamometer.³¹ Left leg power and torque were measured in flexion and extension. Left leg flexion and extension was measured in a standard seating position as recommended by the manufacturer of the Keylink Kinitech Dynamometer.

Seating position was adjusted for height and the angle of the hip and knee were standardised. The highest reading of three measures for each were taken. Left Leg Extensor maximum power (LLExtmp) and Left Leg Extension peak Torque (LLExtpt) and Left Leg Flexor maximum power (LLFxmpt) and Left Leg Flexor peak torque (LLFlxpt) were measured.

Blood samples were collected to measure serum calcium, phosphate, creatinine, albumin, alkaline phosphatase, intact parathyroid hormone (PTH), and 25 hydroxyvitamin D (25OHD). The blood samples were taken in standardised tubes as recommended by the local pathology centre and the reference limits were as standardised for the local population.

Blood samples were collected in the morning on the day of the muscle strength assessment. All blood tests were performed at the one pathology centre. 25OHD was determined by radioimmunoassay using the Diasorin kit. The confidence values at 37 and 135 nmol/L were 10.8% and 8.1% respectively.

Statistical analyses—The data were entered into an SPSS software database and analysed by a biostatistician. Descriptive statistics were performed including mean, standard deviation (SD), and range. Univariate correlations (Pearson's) for normally distributed variables and Spearman's for non normally distributed variables were performed looking for association between 25OHD, functional and biochemical parameters, and between muscle strength, functional and biochemical parameters.

Stepwise multivariate analysis was performed looking for significant associations between muscle strength and age, biochemical, and functional parameters. The t-test and one-way ANOVA were used to assess differences between groups. A p value of <0.05 is considered significant.

Results

Of the 365 patients mailed questionnaires, 105 subjects agreed to participate in this cross sectional study and were enrolled. A total of 99 subjects adequately completed all assessments and were included in the muscle strength analysis. Of the 6 excluded subjects, 3 had primary hyperparathyroidism, 2 had no serum 25OHD measurement, and 1 had difficulty completing the muscle strength assessment.

All subjects were female with a mean age of 79.5 with a standard deviation of 7.9 and a range of 61 to 95 years. All patients enrolled had sustained a previous long-bone fracture. Thirty-four percent had sustained a lower limb fracture (hip) only, and 53% an upper limb fracture (wrist or humerus) only. Thirteen percent of subjects had sustained both upper and lower limb fractures.

The mean 25OHD level of the cohort was 52.0 nmol/L (SD 22.3) with a range of 16–159 (reference limits >50 nmol/L). Only 10% were taking vitamin D either as simple vitamin D or as multivitamin supplements. The values of the functional and biochemical parameters assessed are reported in Table 1.

Table 2 describes the univariate associations between 25OHD and age, functional, and biochemical assessments. All functional assessments were significantly associated with measured serum 25OHD apart from the patients' age, Berg Balance Scale, and the depression scale.

Table 1. Mean (SD), minimum, and maximum values for age, functional, and biochemical measures of patients

Measure (reference range)	Number	Mean	SD	Minimum	Maximum
Age (years)	105	79.5	7.9	61	95
MMSE (0–30)	97	28.5	1.7	23	30
FAI (0–45)	91	29.4	8.6	0	45
BASDEC (0–20)	85	3	3	0	16
RPH (outdoor score) (0–7)	94	4.8	1.5	0	7
FES (0–10)	94	8	1.8	3	10
TUAG (normal <12 sec)	93	16.9	7.7	7	49
BBS (0–56)	95	57.4	9.9	29	74
Calcium (2.15–2.55 mmol/L)	99	2.4	0.1	2.15	2.83
Phosphate (0.8–1.4 mmol/L)	96	1.1	0.2	.51	1.69
Creatinine (50–95 umol/L)	101	79.2	22.6	46	148
Albumin (35–50 g/L)	102	40.8	2.5	33	47
ALP (30–135 U/L)	94	85.9	29.4	19	206
PTH (0.9–9 pmol/L)	100	5.6	5.2	.9	43.0
25OHD (50–160 nmol/L)	103	51.9	22.3	16	159

SD: Standard Deviation; **MMSE:** Mini Mental State Examination; **FAI:** Frenchay Activities Index; **BASDEC:** Brief Assessment Schedule Depression Cards **FES:** Falls Efficacy Scale; **RPH:** Royal Perth Hospital; **TUAG:** Timed “Up & Go” Score; **BBS:** Berg Balance Scale; **ALP:** Alkaline Phosphatase; **PTH:** Parathyroid Hormone; **25OHD:** 25 hydroxyvitamin D; **g/L:** grams per litre; **mmol/L:** Millimole per litre; **umol/L:** Micromole per litre; **pmol/L:** Picomole per litre **U/L:** Units per litre.

Table 2. Association between 25 hydroxyvitamin D and age, functional, and biochemical measures

Measure	Number	Correlation (r)	p value
Age	103	-0.05	0.63
MMSE	95	0.22*	0.03
BASDEC	84	-0.13	0.25
FAI	90	0.23*	0.03
RPH (outdoor score)	93	0.30**	0.002
FES	93	0.25*	0.01
TUAG	91	0.19	0.06
BBS	94	0.15	0.14
Calcium	98	-0.05	0.62
Phosphate	95	-0.12	0.27
Creatinine	100	0.05	0.59
Albumin	101	0.32**	0.001
PTH	100	-0.22*	0.03

MMSE: Mini Mental State Examination; **BASDEC:** Brief Assessment Schedule Depression Cards **FAI:** Frenchay Activities Index; **RPH:** Royal Perth Hospital; **FES:** Falls Efficacy Scale; **TUAG:** Timed “Up & Go” Score; **BBS:** Berg Balance Scale; **PTH:** Parathyroid Hormone; *p<0.05; **p<0.01.

Albumin and PTH were the only biochemical assessments associated with measured serum 25OHD. There was a positive association with albumin and a negative association with PTH. The two factors most strongly associated with 25OHD were serum albumin (r=0.32, p=0.001) and the RPH outdoor score (r=0.30, p=0.002).

Table 3 describes the significant univariate associations between muscle strength and age, functional and biochemical assessments. Although most of the functional

assessments were associated with muscle strength, serum 25OHD level was the only biochemical assessment associated with muscle strength.

Table 3. Association between muscle strength and age, biochemical, and functional measures

Measure	Muscle strength							
	LLExtpt		LLExtmp		LLFlxpt		LLFlxmp	
	r value	p value	r value	p value	r value	p value	r value	p value
Age	-0.304**	0.002	-0.295**	0.003	-0.248**	0.004	-0.248*	0.014
MMSE	0.329**	0.001	0.246*	0.019	0.330**	0.001	0.147	0.163
BASDEC	-0.140	0.215	-0.157	0.164	-0.233*	0.037	-0.215	0.055
FAI	0.147**	<0.001	0.377**	<0.001	0.419**	<0.001	0.310**	0.004
RPH (outdoor score)	0.309**	0.003	0.298**	0.005	0.309**	0.003	0.258*	0.015
FES	0.368**	<0.001	0.307**	0.003	0.325**	0.002	0.212*	0.046
TUAG	-0.447**	<0.001	-0.408**	<0.001	-0.464**	<0.001	0.361**	0.001
BBS	0.407**	<0.001	0.383**	<0.001	0.375**	<0.001	0.279**	0.007
25OHD	0.424**	<0.001	0.427**	<0.001	0.315**	0.002	0.252*	0.012

LLExtpt: Left Leg Extensor Peak Torque; **LLExtmp:** Left Leg Extensor Max Power; **LLFlxpt:** Left Leg Flexor Peak Torque; **LLFlxmp:** Left Leg Flexor Max Power; **MMSE:** Mini Mental State Examination; **BASDEC:** Brief Assessment Schedule Depression Cards **FAI:** Frenchay Activities Index; **RPH:** Royal Perth Hospital; **FES:** Falls Efficacy Scale; **TUAG:** Timed “Up & Go” Score; **BBS:** Berg Balance Scale; **25OHD:** 25 hydroxyvitamin D; *p<0.05; **p<0.01.

Table 4. Multivariable associations between muscle strength and age, biochemical, and functional measures

Measure	Muscle strength							
	LLExtpt		LLExtmp		LLFlxpt		LLFlxmp	
	r value	p value	r value	p value	r value	p value	r value	p value
25OHD	0.489**	<0.001	0.476**	0.001	0.367*	0.019	0.259	0.055
BBS	0.310*	0.020	0.272*	0.043	0.198	0.148	0.206	0.125
TUAG	-0.161	0.241	-0.125	0.362	-0.303*	0.023	-0.238	0.075

Model includes age and all biochemical and functional measures. Only those measures with significant associations are shown. **LLExtpt:** Left Leg Extensor Peak Torque; **LLExtmp:** Left Leg Extensor Max Power; **LLFlxpt:** Left Leg Flexor Peak Torque; **LLFlxmp:** Left Leg Flexor Max Power; **25OHD:** 25 hydroxyvitamin D; **BBS:** Berg Balance Scale; **TUAG:** Timed “Up & Go” Score; *p<0.05; **p<0.01.

Table 4 describes the significant multivariate associations between muscle strength and all other parameters measured (age, biochemical, and functional). In the multiple regression model, 25OHD was significantly associated with both extensor assessments (LL Extpt r=0.489, p<0.001 and LL Extmp r=0.476, p=0.001) as well as the flexor PT (r=0.367; p=0.019) assessment, and showed a strong trend to an association with flexor MP (r=0.259, p=0.055).

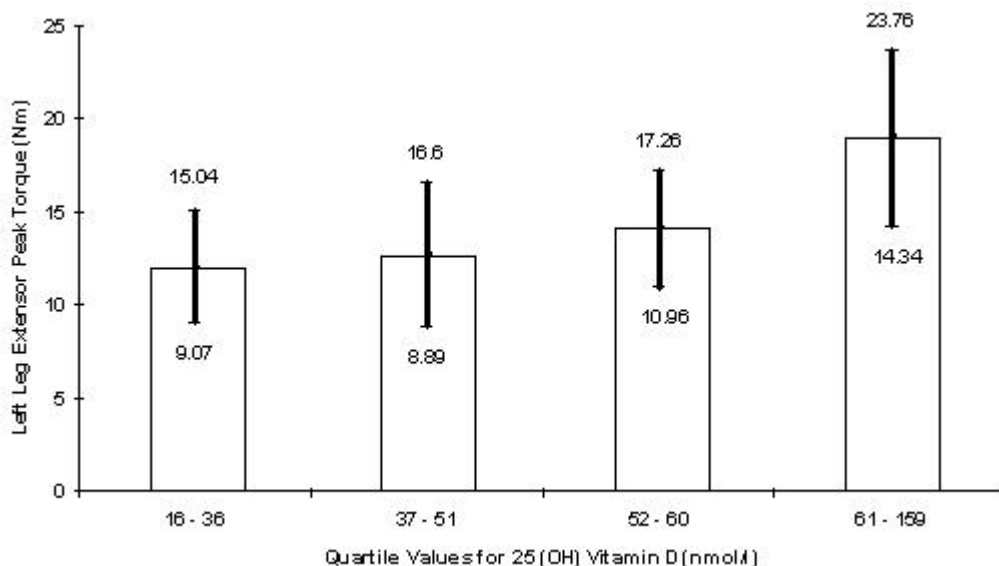
Only two other factors (both functional) showed any association with muscle strength in the multiple regression model. Berg Balance was associated with extensor strength while TUAG was inversely associated with left leg flexor PT only. Site (upper or lower limb) and side of fracture (left or right) did not change the association between muscle strength and 25OHD and were non significant associations in the multiple regression model.

The functional assessments with no significant association in the regression model included MMSE, BASDEC, FAI, RPH outdoor score, and FES. The biochemical assessments with no significant association in the regression model included calcium, phosphate, albumin, alkaline phosphatase, and parathyroid hormone.

Forty-seven patients had a 25OHD level <50 nmol/L and 14 patients had a 25OHD <30 nmol/L. The association between muscle strength and 25OHD was strongest in the sub-group with 25OHD levels >50 nmol/L ($p < 0.01$ for all four muscle strength assessments with the r value ranging between 0.46 and 0.51).

The association between muscle strength and 25OHD levels was not significant in subjects with 25OHD levels <50 nmol/L ($p > 0.05$). Using one-way ANOVA, the quartile with the highest 25OHD level (>60 nmol/L) demonstrated the highest mean muscle strength (Figure 1). However, this association was only significant for LL Extpt ($p = 0.035$) but not LL Extmp ($p = 0.065$), LL Flxpt ($p = 0.11$), or LL Flxmp ($p = 0.25$).

Figure 1. Mean and 95% confidence intervals of muscle strength (left leg extensor peak torque) for quartiles of 25 hydroxyvitamin D



Subgroup analysis was undertaken to compare muscle strength and 25OHD between the group with left versus right-hip fracture and those with upper-limb and lower-limb fractures. There was no significant difference in left-leg muscle strength based on side of hip fracture ($p > 0.05$). However, those with upper-limb fracture only had higher left-leg muscle strength than those with lower-limb fracture ($p < 0.05$). There was no significant difference in 25OHD levels in these subgroups ($p > 0.05$).

Discussion

Vitamin D deficiency is being increasingly identified as a significant problem in older patients.^{11,12,32} Its impact on bone has been extensively investigated. However, its impact on muscle strength and falls is less well understood.

Given the high incidence of falls, osteoporosis, and vitamin D deficiency in older individuals, establishing an association and correcting vitamin D deficiency may be potentially beneficial in improving muscle strength, reducing falls, and hence reducing fractures.

This cross sectional study looked at the potential association between muscle strength and 25OHD deficiency in patients previously admitted with fracture, including 46% with a previous hip fracture.

We found a moderate and significant positive correlation between muscle strength and 25OHD. Although a number of factors appear to be associated with muscle strength on univariate analysis, the only factors independently associated after correction for other factors in a multiple stepwise regression analysis were 25OHD, the Berg Balance Scale, and the Timed "Up & Go" score.

The 25OHD level appears to be the only consistent significant association with left-leg muscle strength with a moderate positive correlation. The association with Berg Balance and Timed "Up & Go" is weaker and only associated with some parameters of muscle strength. Although side of fracture does not appear to influence muscle strength, the presence of lower limb fracture does appear to result in worse muscle strength.

The main limitation of this study is the relatively low response rate. In addition, as with other similar studies, frailer subjects and those with cognitive impairment were excluded on the basis that they could not perform the muscle strength assessment.

These are both groups that are more likely to have been vitamin D deficient. The relatively high mean 25OHD level of 52 nmol/L reflects this and unfortunately the relatively small sample size does not allow for adequate subgroup analysis.

The stronger association between 25OHD level and muscle strength parameters in the sub-group with levels >50 nmol/L is unexpected, as we would have predicted a stronger association in the group deemed to be vitamin D deficient i.e. <50 nmol/L. This may reflect a threshold level of 25OHD which must be reached before vitamin D starts to affect muscle strength in patients.

It would also strongly support the argument that 25OHD levels need to be maintained well above 50 nmol/L for adequate replacement and benefit in terms of muscle strength. This is an area that certainly requires further study especially with regards to the impact of replacement of vitamin D in subjects with levels below 50 nmol/L and the most appropriate level desirable for greatest benefit in terms of muscle strength.

Higher levels may be the goal rather than aiming for low normal levels for greater benefit in terms of muscle strength and possibly bone.

The strength of this study is that it looked at a high-risk group who are more susceptible to vitamin D deficiency due to reasons of relative frailty, previous falls,

and fractures. This is the population that would need to be targeted as a priority in terms of vitamin D replacement.¹²

In patients with osteoporosis, the goal should be to reduce fracture risk. To achieve this we need to look beyond the improvement of bone strength and quality. Falls prevention is another obvious objective.

As muscle weakness is a major cause of falls, improving muscle strength is an important component of this strategy. Hence identifying and treating conditions likely to be associated with reduced muscle strength (such as vitamin D deficiency) is an area that warrants further investigation. And to confirm the causal association between vitamin D and muscle strength, a large randomised controlled intervention trial is needed.

Competing interests: None.

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References:

1. Sanders KM, Nicholson GC, Ugoni AM, et al. Health burden of hip and other fractures in Australia beyond 2000. Projections based on the Geelong Osteoporosis Study. *Med J Aust.* 1999;170:467–70.
2. Tinetti ME, Williams CS. Falls, injuries due to falls, and the risk of admission to a nursing home. *N Engl J Med.* 1997;337:1279–84.
3. Seeman E, Eisman JA. Treatment of osteoporosis: why, whom, when and how to treat. The single most important consideration is the individual's absolute risk of fracture. *Med J Aust.* 2004;180:298–303.
4. Delmas PD. Treatment of postmenopausal osteoporosis. *Lancet.* 2002;359:2018–26.
5. Tinetti ME, Baker DI, McAvay G, et al. A multifactorial intervention to reduce the risk of falling among elderly people living in the community. *N Engl J Med.* 1994;331:821–7.
6. Boonen S, Aerssens J, Dequeker J. Fractures of the proximal femur: Implications of age-related decline in muscle function. *Journal Orthop Rheumatol.* 1995;8:127–33.
7. Nguyen TV, Eisman JA, Kelly PJ, et al. Risk factors for osteoporotic fractures in elderly men. *Am J Epidemiol.* 1996;144:255–63.
8. Stanley ST, Marshall RN, Tilyard MW, et al. Skeletal muscle mechanics in osteoporotic and nonosteoporotic postmenopausal women. *Eur J Appl Physiol Occup Physiol.* 1994;69:450–5.

9. Murray M, Duthie E, Gambert S, et al. Age related differences in knee muscle strength in normal women. *J Gerontol.* 1985;40:275–80.
10. Hyatt RH, Whitelaw MN, Bhat A, et al. Association of muscle strength with functional status of elderly people. *Age Ageing.* 1990;19:330–6.
11. Inderjeeth CA, Nicklason F, Al-Laham, et al. Vitamin D deficiency and secondary hyperparathyroidism: clinical and biochemical associations in older non-institutionalised Southern Tasmanians. *Aust N Z J Med.* 2000;30:209–14.
12. Inderjeeth CA, Barrett T, Al-Laham Y, et al. Seasonal variation, hip fracture and vitamin D levels in Southern Tasmania. *N Z Med J.* 2002;115:183–95.
<http://www.nzma.org.nz/journal/115-1152/2230/content.pdf>
13. Costa EM, Blau HM, Feldman D. 1,25-dihydroxyvitamin D3 receptors and hormonal responses in cloned human skeletal muscle cells. *Endocrinology.* 1986;119:2214–20.
14. Birge SJ, Haddad JG. 25-hydroxycholecalciferol stimulation of muscle metabolism. *J Clin Invest.* 1975;56:1100–107.
15. Gloth FM, Tobin JD. Vitamin D deficiency in older people. *J American Geriatr Soc.* 1995;43:822–8.
16. Bischoff HA, Stahelin HB, Urscheler N, et al. Muscle strength in the elderly: It's relation to vitamin D metabolites. *Arch Phys Med Rehabil.* 1999;80:54–8.
17. Sorensen OH, Lund BI, Saltin B, et al. Myopathy in bone loss of ageing: improvement by treatment with 1 alpha-hydroxycholecalciferol and calcium. *Clin Sci (Lond).* 1979;56:157–61.
18. Kocian J. Anabolic effects of vitamin D in patients with osteomalacia. *Vnitr Lek.* 1989;35:1211–19.
19. Grady D, Halloran B, Cummings S, et al. 1,25-dihydroxyvitamin D3 and muscle strength in the elderly. A randomized controlled trial. *J Clin Endocrinol Metab.* 1991;73:1111–17.
20. Bischoff H, Stahelin HB, Dick W, et al. Effects of vitamin D and calcium supplementation on falls: a randomised controlled trial. *J Bone Miner Res.* 2003;18:343–51.
21. Zamboni M, Zoico E, Tosoni P, et al. Relation between vitamin D, physical performance and disability in elderly persons. *J Gerontol A Biol Sci Med Sci.* 2002;57:M7–11.
22. Pfeifer M, Begerow B, Minnie HW. Vitamin D and muscle function. *Osteoporos Int.* 2002;13:187–194.
23. Inderjeeth CA, Glennon D, Petta A. Osteoporosis awareness, investigation and treatment of patients discharged from a tertiary public teaching hospital. *Intern Med J.* 2006;36:547–51.
24. Piotrowski A, Cole J. Clinical measures of balance and function assessment in elderly persons. *Australian Physiotherapy.* 1994;40:183–8.
25. Wade DT, Leigh-Smith J, Langton-Hewer R. Social activities after stroke: measurement and natural history using the Frenchay Activities Index. *Int J Rehabil Med.* 1985;7:176–81.
26. Shah S, Vanclay F, Cooper B. Improving the sensitivity of the Barthel Index for stroke rehabilitation. *J Clin Epidemiol.* 1989;42:703–9.
27. Tinetti ME, Richman D, Powell L. Falls efficacy as a measure of fear of falling, *J Gerontol.* 1990;45:239–43.
28. Podsiadlo D, Richardson S. The timed “Up & Go”: a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc.* 1991;39:142–8.
29. Folstein MF. “Mini-mental state”. A practical method for grading the cognitive state of patients for the clinician. *J Psychiat Res.* 1975;12:189–98.
30. Adshear F, Cody DD, Pitt B. BASDEC: a novel screening instrument for depression in elderly medical inpatients. *BMJ.* 1992;305:397.

31. Gilbey H, Ackland TR, Wang A, et al. Exercise improves early functional recovery after total hip arthroplasty. *Clin Orthop Relat Res.* 2003;408:193–200.
32. Lucas JA, Bolland MJ, Reid IR, et al. Determinants of vitamin D status in older women living in a subtropical climate. *Osteoporos Int.* 2005;16(12):1641–8.