AIMS Medical Science, 3(4): 345–358.
DOI: 10.3934/medsci.2016.4.345
Received 16 November 2016,
Accepted 24 November 2016,
Published 1 December 2016

http://www.aimspress.com/journal/medicalScience

Review

Narrative Review of Vitamin D and Its Specific Impact on Balance Capacity in Older Adults

Ray Marks [1, 2, *]

[1] Department of Health, Physical Education, Gerontological Studies and Services, York College, City University of New York;

[2] Department of Health and Behavior Studies, Teachers College, Columbia University, New York, NY 10027, USA

*** Correspondence:** Email: rm226@columba.edu; Tel: +1-212-678-3445; Fax: +1-212-678-8259.

Abstract: Introduction and Aims: Falls injuries among older adults, a widespread well-established contributor to high disability levels, excess morbidity and mortality rates, have many causes. This review examines the association between vitamin D levels and postural stability or balance control—a fairly consistent predictor of falls among older adults. **Materials and Method:** All relevant English language peer reviewed research publications detailing the relationship between vitamin D levels and balance control among the elderly were sought. Key words included "*Vitamin D and Balance or Postural Control*." Databases used were Academic Search Complete, PubMed, Scopus, and Web of Science. **Results:** Analysis showed no consistent association to exist between the key variables of interest examined-indeed, despite years of study, there as many positive studies as negative studies, regardless of study design. **Conclusion:** More research is needed to support the use of vitamin D supplementation for purposes of improving balance capacity among older adults. Geriatric clinicians can however, expect this form of intervention to be more protective then not against falls injuries among those with both concomitant vitamin D deficiencies and poor balance control.

Keywords: aging; balance; falls; older adults; therapeutic use of vitamin D

1. Introduction

For more than 30 years, falls have been a leading cause of death among older persons in the United States, and elsewhere [1,2]. Among those who survive, many, previously unimpaired, may experience mobility and independence losses, plus a greater risk of premature mortality [3].

Fortunately, cumulative evidence indicates several potentially modifiable factors can influence the risk of falling and sustaining a disabling injury. These include, but are not limited to deficient muscle strength, confusion, sensory losses, and poor postural control or balance impairments [1,3–5].

In particular, among recent discussions concerning falls risk factors among the elderly, the question of whether there is a possible link between any increased risk of falling as a result the influence vitamin D on balance capacity has been raised. If it can be shown that vitamin D, a hormone associated with many important body functions [2,4] and that can be delivered in the form of a daily supplement, or via and intramuscular injection, the ingestion of certain foods, and/or sunlight exposure is a powerful mediating force that influences balance capacity, this may have a highly positive influence on reducing falls risk among the elderly [6].

That is, in addition to converging research that implies optimal levels of vitamin D, potentially impact muscle function, bone quality, cartilage metabolism, pain, depression, and comorbid health conditions favorably, the presence of optimal levels of vitamin D may play an important role in impacting balance capacity, thus reducing the risk of falls attributable to balance related impairments. This does not contradict or negate the use of supervised physical activity programs- or multi-component programs or selected therapies such as whole body vibration training [1] or environmental modifications [4] as being beneficial to reducing falls risk among the elderly, but suggests that instead of costly multidimensional approaches that may still fail to produce the desired outcomes-if the individual is vitamin D deficient, and/or is on psychoactive drugs for depression, and has poor balance capacity, regardless of improved footwear, and dietary practices, vitamin D intake might be favorably modified to influence balance and falls risk in a favorable way.

Consider too, the problems of adhering to recommendations to carry out progressive resistance exercises on a consistent basis, in addition to aerobic, and flexibility exercises, as a falls risk prevention strategy [1], among the older adult, especially those who are already health compromised. In addition, older persons at risk for falling may already be vitamin D deficient, thus rendering muscle intervention outcomes suboptimal at best. Moreover, falls can actually occur during exercise if the individual is weak, or if exercise is fatiguing, or if balance is suboptimal due to structural problems. Finally, even if the individual falls and fractures a bone, it is accepted they will be more likely to achieve a better outcome if they do not have any prevailing vitamin D deficiency if compared to those who have a prevailing deficiency.

Even though many researchers have attempted to examine the role of multiple measures applied concurrently to reduce falls risk among the elderly-how these can be applied in real life circumstances with fidelity and what specifically is required in this regard-remains quite vague.

There is also no convincing evidence that single measures will not be as effective as multiple measures in efforts to prevent falls among older persons. In addition, what the active ingredient is in multiple directed interventions is not readily discernable in related reports, eg., Palvenen et al. [7] and how well these studies control for attention is unclear.

There is further controversy as to the influence of vitamin D supplementation on falls risk [references 8 versus 9], and specifically as to whether balance is positively affected in the presence of adequate vitamin D serum levels [6,9]. Also in question are the mechanisms that account for improvements in some balance measures following vitamin D supplementation [10] While Muir et al. [11] concluded that supplemental vitamin D of approximately 800–1000 IU has consistent balance benefits in older adults, only 7/12 studies in a 2015 a meta-analysis of multifactorial studies to reduce falls reported this to be a fact [9]. Before continuing to base recommendations made in the clinic on highly conflicting data, it is our view that the current as well as the past literature should be carefully examined, and some explanation for the conflicting results should be forthcoming.

1.1. Aims

This review aimed to access and examine the available information related to the claim that an appropriate daily supplement of vitamin D or efforts to ensure optimal vitamin D serum levels via other methods may go a long way to reducing the risk of falls due to poor balance capacity among older adults. That is, the paper specifically examines if vitamin D supplementation is likely to positively affect balance capacity among older individuals, if they present with any deficiency or insufficiency.

1.2. Implications

The question addressed in this review was deemed important to resolve because if proved efficacious, vitamin D supplementation is likely to be highly advantageous clinically because it is easy to adhere to, as well as economically feasible, and practical, when compared to exercise and cognitive approaches employed in falls prevention efforts that are often challenging, time consuming, and carried out inconsistently.

2. Materials and Methods

To address the topic highlighted in this present review, a very brief summary of the traditional approaches to falls prevention, followed by the research on vitamin D is discussed. Thereafter, studies that have specifically examined vitamin D levels and their association to balance capacity in older adults are described. To this end, data in primary repositories on the topic at hand were sought using key words such as falls, vitamin D, balance, postural control. Excluded from the detailed descriptive analysis were studies of subjects younger than 60 years of age, those with neurological

diseases, research studies conducted prior to 2011, as these have been detailed in Muir et al. [11]. Others were excluded if they did not focus on the topic of interest, or were written in a language other than English or were not complete articles. A sample of the extent of the findings conducted in Scopus. Academic Search Complete, Web of Science, PUBMED and Cinahl is shown below and includes the time period of 1980-June, 2016. Both cross sectional, as well as prospective studies, along with observational and controlled studies were deemed acceptable, and only a narrative review of these data was attempted.

3. Search Results

Using the search term Falls Prevention, there were 12070 possible PUBMED articles; 7598 in last 10 years; and 4190 in the last 5 years. The search term Vitamin D yielded 68265 articles; 30815 in the last 10 years, and 19462 in the last 5 years. The combination of Vitamin D and Falls Prevention yielded 685 articles, 485 in last 10 years, and 236 in last 5 years. The combined terms Vitamin D and Balance yielded 679 articles in the last 10 years and 391 in the last 5 years. Many articles did not however focus on the topic at hand. Thus one can say that very few articles in addition to those 13 presented by Muir et al. [11] prevail, however, all are included in some way in this report.

3.1. Falls prevention programs and vitamin D

A number of review articles and stand-alone reports have concluded that it is important to utilize a multifactorial program approach in the context of preventing falls among older adults [7] given the multiple determinants of falls risk. While there is reasonable support for this idea, there is a limited understanding of which strategies will yield the desired outcomes most effectively, and why. Among the observations made in this realm Bischoff-Ferrari et al. [12] demonstrated a significant impact of vitamin D plus calcium on falls injury rates that was attributable in part to improvements in static and dynamic balance. Kormaz et al. [13] too, found vitamin D to be necessary for enhancing muscle strength, range of motion, and balance, which could potentially reduce falling rates among postmenopausal women with osteoporosis.

Thus, similar to exercise, often applied in the context of falls prevention programs, some research shows vitamin D supplementation, may impact positively on several factors often associated with falls risk, including physical and cognitive health in older non-demented individuals [14], muscle strength and function [4,15–18], chair rising time [4], muscle mass and contractile capacity [19], navigational and cognitive performance [20]), postural adaptations [21], postural sway, and lower extremity and physical performance [18] in the elderly [22]. Other research shows low vitamin D levels, in contrast, are associated with decreases in muscle mass, strength and contractile capacity, as well as physical performance in older people [20] and balance [23], and possibly on increased falls

risk, but the association between vitamin D and balance performance is not always consistent.

3.2. Balance and vitamin D

A fair number of research studies show balance is a strong predictor of falls in later life [24], and that balance impairments are associated with increased falls rates [25]. Thus treatments than can optimize balance capacity are of high potential import to the well-being of older adults as outlined by Takata [22].

But what is the extent of the evidence for this claim? Below are some recent studies categorized as observational versus intervention studies and their findings.

3.2.1. Observational studies

Contrary to studies that show a relationship between vitamin D levels and various functional parameters, Mathei et al. [26] who investigated the baseline relationship between muscle function and vitamin D status among 367 frail elderly 80 years and older in a prospective study found no significant vitamin D, balance relationship. Only 12.8% of the sample had sufficient vitamin D levels, yet this did not translate into any meaningful association of balance. The static tandem stance balance test-which was assessed as a dichotomized variable may have been too insensitive for assessing challenges or proficiencies in balance capacity during actual functional tasks however, and may warrant more study. Dividing the cohort in to 4 groups of unequal subject numbers based on vitamin D serum levels that may have been less than optimal and who were said to be similar but had somewhat divergent gait scores and hand grip scores may have affected the nature of the associations examined and their observed relationships that did not concur with previous work.

In another study that recently assessed the relationships among vitamin D levels, balance, falls, muscular strength, and quality of life in 46 women with postmenopausal osteoporosis and 46 healthy women, Korkmaz et al. [13] reported that vitamin D has a direct effect on balance. In this study, the balance tests used included the Timed Up and Go and Chair Raising test, and the Berg Balance Test, and although there were no group differences observed, after subdividing the patient group, it was shown those with vitamin D levels greater than 15 ng/ml had significantly better balance than those with vitamin D levels lower than 15 ng/ml as shown by the longer chair rise time and rise times in the group with low vitamin D levels.

In support of the aforementioned study findings, Boersma et al. [27] who examined 145 community dwelling adults over age 65 with at least one recent falls injury or episode noted their measures of postural instability assessed using a computerized virtual reality system that assessed limits of stability and center of pressure under eyes closed on foam and visio-vestibular stimulation were negatively correlated with prevailing levels of vitamin D after adjusting for demographics, biochemical and anthropometric variables. Similarly Krause et al. [28] found postural body sway of

342 older individuals was higher in those with vitamin D deficiency.

Akdeniz et al. [29] who evaluated the association between vitamin D and the risk of falling, balance capacity, and lower extremity neuromuscular function among women aged 60 or older also found those with serum vitamin D levels greater than 50.0 nmol/l to have superior balance control. This group used an instrument known as Tetrax posturography, and they classified 200 women based on their vitamin D levels into a hypo-vitaminosis group (less than 50.0 nmol/l) and a normal group (50.0 nmol/l or more). Their data revealed a significant association between the subject's serum vitamin D levels and their stability scores as well as their lower extremity functional scores, and falling risk.

Menant et al. [31] however, found slightly different results in that the presence of a vitamin D deficiency or insufficiency reduced leaning balance, but not postural sway. The results of this study involving a sample consisting of 463 community-dwelling older men and women 70–90 years of age also showed that after controlling for age and body mass, these vitamin D levels and leaning balance measures were more strongly related in men than women.

In related basic research, an important finding that may help to resolve the issue of whether a vitamin D deficiency may indeed affect balance is the observation of the impact of vitamin D on increasing the risk for developing otolith dysfunction of both the utricle and saccule of the inner ear. This was suggested by a study that showed a high prevalence of abnormal ocular vestibular-evoked myogenic potentials (oVEMP) and cervical vestibular-evoked myogenic potentials in the context of vitamin D deficiency. [30]. If this can be shown to be a robust finding, it further suggests there is at least one powerful mechanism explaining any probable vitamin D - balance association.

3.2.2. Intervention and prospective studies

Among controlled or prospective studies that have examined vitamin D and balance associations, Dukas et al. [15] who studied 237 participants with a mean age of 75.9 years who received daily treatment of a form of vitamin D known as alfacalcidol found that when controlling for age, gender and body mass, treatment with vitamin D significantly increased balance performance at 3 months. This effect increased after six months of therapy and was accompanied by a decrease in the absolute number of fallers and falls, compared to the six months before starting the therapy.

Bogaerts et al. [1] who compared the effect of a regular dosage versus a higher dosage of vitamin D on 113 older individuals randomized to a vibration exercise group or control group found contrary results. Studying only healthy adults 70 years, they measured dynamic balance along with falls risk before and after six months. No differences in any outcome were predicted by vitamin D dosages, however, although sway velocity improved in the experimental group. There was no sham control group but it still seemed that a link between vitamin D and balance as reported by the Timed get up and Go Test which improved in both experimental and control groups to the same extent could not be discounted.

The outcomes observed by Bogaerts et al. [1] were also dissimilar to those of Annweiler et al. [21] where higher serum vitamin D concentrations were associated with better balance among older adults with supra-optimal vitamin D status. These were aligned however, with those of Bird et al. [25] who found no association between seasonal vitamin D variations and postural sway measures in independently mobile older adults assessed prospectively.

Moreover, a study by Iwamoto and Saito [19] who conducted an open-label randomized controlled trial designed to clarify the effect of a vitamin D derivative on body balance found there was no significant improvement in the uni-pedal standing time measure in the experimental group, compared with the control group, even though chair-rising time decreased significantly in that group compared with the control group. In this study, 106 postmenopausal women with osteoporosis, average age 70.8 years were randomized into two equal size groups: a bisphosphonate group (control group) and a bisphosphonate plus vitamin D group. Biochemical markers, uni-pedal standing time-a measure of balance, and five-repetition chair-rising time (a measure of muscle power) were evaluated before and after the 6-month study period. After the 6-month treatment period, the researchers found the bone turnover markers had decreased significantly from the baseline values but this was similar in the two groups. The present study showed that although the intervention improved the chair-rising time of postmenopausal osteoporotic women treated with bisphosphonates, it had no effect on the functional balance measure.

Uusi-Rasi et al. [32] however, concluded vitamin D supplementation and exercise recommended for prevention of falls for older people were not efficacious, but that strength and balance training were more helpful. The cohort were all 70 years and older with a falls history who participated in a 2-year randomized, double-blind, placebo-controlled study. The four study groups included a placebo group without exercise, a vitamin D (800 IU/d) group without exercise, a placebo and exercise group, and a vitamin D (800 IU/d) and exercise group. The main outcome assessed monthly was reported falls. Injurious falls and the number of fallers and injured fallers were reported as secondary outcomes. As well, bone density, physical functioning (muscle strength, balance, and mobility), and vitamin D metabolism were assessed. Vitamin D maintained femoral neck bone mineral density and increased tibial trabecular density slightly. However, only exercise improved muscle strength and balance, and vitamin D had no mediating exercise effect on physical functioning.

As outlined by Anek et al. [33], the impact of vitamin D supplementation may be dependent on the extent of the dosage or mode of delivery provided, among other factors. This group showed that high supplementary doses of vitamin D2 improved balance ability at the post test on normal stability surfaces when experimental subjects were compared with a control group ($p < 0.05$). This group divided post-menopausal women into two equal size groups, 26 who received vitamin D supplementation, and 26 who served as a control group. The experimental group received 20,000 IU of vitamin D2 per week, for a period of 4 weeks. The control group did not receive vitamin D2.

Similarly in a study by Cangussu et al. [34], the authors who applied vitamin D supplementation to postmenopausal women fallers found falls rates were almost 50% higher in the control group.

They also found the relative risk for recurrent falls was 2.80 times higher for the control group compared to the experimental group. The experimental group who received the supplementation showed a reduction in body sway in both the antero-posterior and latero-lateral directions, which was taken to indicate a positive independent outcome of isolated vitamin D supplementation on postural balance after 9 months, and the significant falls reduction rate. This body of research seems sound because the researchers used a double-blind, placebo-controlled trial design to examine the post-intervention responses of 160 postmenopausal women randomized into two groups: a vitamin D group of 80 adults that received vitamin D3 supplementation of 1,000 IU/day/orally and a placebo group of 80 women who partook in the study for 9 months. The subjects' postural balance was assessed using stabilometry and falls incidents were recorded by interviews. The subjects'plasma concentration of vitamin D was measured by high-performance liquid chromatography and after 9 months, the mean values of these assays showed the vitamin D levels increased in the experimental group and decreased in the control group.

Other data have shown that intra muscular vitamin D applications can have a marked effect on balance in vitamin D deficient elderly women [35], and that vitamin D supplementation may improve corticospinal neural transmission in older persons [36] as well as gait control [5].

4. Discussion

The recommendation that optimal levels of vitamin D be employed in efforts to prevent falls among older adults is widespread. The possible contribution of improved balance capacity to explain this potential benefit, while grounded in a fairly strong rationale, is less universally demonstrated. Indeed, there are both supportive and non-supportive findings in the recent literature as to whether balance capacity among older adults is heightened or optimized by vitamin D, but it is not clear what explains this difference as the study samples, duration, design, outcomes assessed, vitamin D analogs, definitions, and dosages, and research goals addressed are strikingly diverse. In addition, even among similar study approaches or among positive affirmative studies it is very hard to link the association between balance and vitamin D levels to falls injury rates, as balance tests are not only diverse, but are largely those that capture elements of balance under static or non-functional conditions unrelated to tripping and slipping-associated with most falls that occur during gait (See Box 1). In other cases, tests such as the sit to stand timed tests are used differentially, sometimes to represent balance capacity, or alternately to represent muscle power. Moreover, when falls rate improvements are noted, the use of other falls reduction strategies applied simultaneously and the failure to control adequately for this possibility, as well as the tools used to verify the extent of any falls related injuries, prevents the attribution of any identified balance improvements specifically to vitamin D supplementation, or any related linkage to falls risk. As well, the type of vitamin D correlate being discussed, the modes of obtaining adequate levels of vitamin D, the methods of measuring vitamin D levels, the definition of vitamin D sufficiency versus insufficiency, as well as

dosages of vitamin D employed as a falls prevention strategy are generally quite inconsistent, regardless of study design [40]. In many cases too, baseline vitamin D levels, adherence rates, prevailing health status, degree of outdoor vitamin D exposure, intake of food based vitamin D components, plus post treatment vitamin D levels have not always been clearly delineated or controlled for [37]. There was also variability in types of assays used to measure baseline vitamin D levels among different study populations, varying use of supplementary dosages, calcium co-supplementation, and duration of follow-up [42].

Box 1. Lack of Study Consensus May Reflect Heterogeneity on Several Levels.

Balance Tests and Parameters Employed Including:

Center of pressure assays
Functional reach tests
Limits of stability tests
Medio-lateral sway tests [39]
Postural sway tests with a pressure plate [28]
Postural sway tests using a force platform [25]
Postural sway [in degrees] [44]
Romberg test
Stabilometry using a force platform [34]
Static and dynamic balance tests [1]
Standing balance [24]
Timed get up and go test [5,38]
Trunk angular displacement measures,
Tetrax/computerized posturography [46]
Unipedal stance time

Vitamin D Assays, Derivatives, Terms, or Definitions Employed

Active vitamn D3 analog [22]
Alfacalcidol [38,46]
Calcidiol
Cholecalciferal-vitamin D3 [35]
Eldecalcitol [19]
20,000 IU vitamin D2 per week [33]
800 or 1600 IU vitamin D [1]
800-1000-10,000 IU vitamin D per day [40]
25(OH) D with radioimmuno assay [25,28,44]; high performance liquid chromatography [34]
1000 IU vitamin D3 [34]
8400 IU vitamin D 3 [39]
Serum-hydroxyvitamin D(25-(OH)D) [40]
Serum 25-hydroxyvitamin D [5,6,43]
Supra-optimal vitamin D levels [21]
25-hydroxyvitaminD(25OHD) </=12 microg/l [41]
Intramuscular injection 600,000 IU Ergocalciferol [41]

Research design

Sample studied

However, in light of several favorable study outcomes implicating low vitamin D levels in balance control [44], along with basic research to support both a rationale for these findings as well as a linkage to falls risk, and/or recurrent falls [34], further studies that take into account possible confounding factors listed in Box 2 may be helpful for arriving at a consensus. Indeed, it is believed that resolving this lack of consensus concerning the clinical significance of any vitamin D-balance association among older people can help to offset any potential confusion for practitioners with regard to vitamin D supplementation [40] and is hence an important public health imperative, rather than one solely of scholarly interest.

Box 2. Possible Reasons for Failed Studies.

- Extent and type of vitamin D supplementation
- Failure to control for comorbidities that interfere with vitamin D metabolism
- Failure to control for extraneous sources of vitamin D
- Failure to control for possible dysfunction of vitamin D membrane receptors
- Failure to control for pain, neurological, and musculoskeletal problems that could affect balance
- Insufficient power to demonstrate significant associations
- Insensitive balance test

5. Limitations of This Review

This review has some strengths and weaknesses. One weakness is that it does not include peer reviewed articles that are written in languages other than English, or reside in data bases not examined. Another is that there are very few studies with comparable methodological approaches, thus the reasoning in this review is largely descriptive and presented in narrative form. The search strategy was comprehensive, however, and does represent a fair snapshot of the status of this topic and its variable findings and conclusions.

6. Conclusion

This literature review revealed over 40 scientific papers related to discussions pertaining to the possible association between vitamin D and balance capacity. Due to the vast variations in these reported approaches, and samples studied, it is impossible to effectively produce a valid systematic meta analytic report. With as many positive as negative study findings, the question driving this present review must be resolved by careful future work that is mindful of the weaknesses in the prevailing literature.

In light of the immense burden of falls among older adults and the current inability of clinicians

to recommend the use of vitamin D supplementation as a viable cost-effective falls prevention or supplementary strategy with a high degree of certainty, the provision of more evidence based practice to clarify the subpopulations that are most likely to benefit from treatment in this regard [42] is highly recommended. Such data will also help to further our understanding of the determinants of balance as well as falls risk among the elderly.

Conflict of Interest

The authors declare no conflict of interest.

References

1. Bogaerts A, Delecluse C, Boonen S, et al. (2011) Changes in balance, functional performance and fall risk following whole body vibration training and vitamin D supplementation in institutionalized elderly women. A 6 month randomized controlled trial. *Gait Posture* 33: 466-472. doi: 10.1016/j.gaitpost.2010.12.027.
2. Luk JK, Chan TY, Chan DK (2015) Falls prevention in the elderly: translating evidence into practice. *Hong Kong Med J* 21: 165-171. doi: 10.12809/hkmj144469.
3. Fraix M (2012) Role of the musculoskeletal system and the prevention of falls. J *Am Osteopath Assoc* 112: 17-21.
4. Shuler FD, Schlierf T, Wingate M (2014) Preventing falls with vitamin D. *W V Med J* 110: 10-12.
5. Beauchet O, Launay CP, Fantino B, et al. (2015) Motor imagery of gait in non-demented older community-dwellers: performance depends on serum 25-hydroxyvitamin D concentrations. *Age (Dordr)* 37: 18. doi: 10.1007/s11357-015-9755-3.
6. Dawson-Hughes B (2012) Serum 25-hydroxyvitamin D and muscle atrophy in the elderly. *Proc Nutr Soc* 71: 46-49. doi: 10.1017/S0029665111003260.
7. Palvanen M, Kannus P, Piirtola M, et al. (2014) Effectiveness of the Chaos Falls Clinic in preventing falls and injuries of home-dwelling older adults: a randomised controlled trial. *Injury* 45: 265-271. doi: 10.1016/j.injury.2013.03.010
8. Guo JL, Tsai YY, Liao JY, et al. (2014) Interventions to reduce the number of falls among older adults with/without cognitive impairment: an exploratory meta-analysis. *Int J Geriatr Psychiatry* 29: 661-669. doi: 10.1002/gps.4056.
9. Stubbs B, Brefka S, Denkinger MD (2015) What works to prevent falls in community-dwelling older adults? Umbrella review of meta-analyses of randomized controlled trials. *Phys Ther* 95: 1095-1110. doi: 10.2522/ptj.20140461.

10. Aung K (2014) Review: in postmenopausal women and older men, vitamin D plus calcium reduces some fractures. *Ann Intern Med* 161: JC5. doi: 10.7326/0003-4819-161-6-201409160-02005.
11. Muir SW, Montero-Odasso M (2011) Effect of vitamin D supplementation on muscle strength, gait and balance in older adults: a systematic review and meta-analysis. *J Am Geriatr Soc* 59: 2291-2300. doi: 10.1111/j.1532-5415.2011.03733.x.
12. Bischoff-Ferrari HA, Conzelmann M, Stähelin HB, et al. (2006) Is fall prevention by vitamin D mediated by a change in postural or dynamic balance? *Osteoporos Int* 17: 656-663.
13. Korkmaz N, Tutoğlu A, Korkmaz I (2014) The relationships among vitamin D level, balance, muscle strength, and quality of life in postmenopausal patients with osteoporosis. *J Phys Ther Sci* 26: 1521-1526. doi: 10.1589/jpts.26.1521.
14. Beauchet O, Annweiler C, Verghese J, et al. (2011) Biology of gait control: vitamin D involvement. *Neurolog* 76: 1617-1622. doi: 10.1212/WNL.0b013e318219fb08.
15. Dukas L, Schacht E, Runge M, et al. (2010) Effect of a six-month therapy with alfacalcidol on muscle power and balance and the number of fallers and falls. *Arzneimittel forschung* 60: 519-525. doi: 10.1055/s-0031-1296321.
16. Muschitz C, Kocijan R, Stütz V, et al. (2015) Vitamin D levels and comorbidities in ambulatory and hospitalized patients in Austria. *Wien Klin Wochenschr* 127: 675-684. doi:10.1007/s00508-015-0824-5.
17. Pirotta S, Kidgell DJ, Daly RM (2015) Effects of vitamin D supplementation on neuroplasticity in older adults: a double-blinded, placebo-controlled randomised trial. *Osteoporos Int* 26: 131-140. doi: 10.1007/s00198-014-2855-6.
18. Walrand S (2016) Effect of vitamin D on skeletal muscle. *Geriatr Psychol Neuropsychiatr Vieil* 21.
19. Iwamoto J, Sato Y (2014) Eldecalcitol improves chair-rising time in postmenopausal osteoporotic women treated with bisphosphonates. *Ther Clin Risk Manag* 10: 51-59. doi: 10.2147/TCRM.S54772.
20. Marcelli C, Chavoix C, Dargent-Molina P (2015) Beneficial effects of vitamin D on falls and fractures: is cognition rather than bone or muscle behind these benefits? *Osteoporos Int* 26: 1-10. doi: 10.1007/s00198-014-2829-8.
21. Annweiler C, Montero-Odasso M, Schott AM, et al. (2010) Fall prevention and vitamin D in the elderly: an overview of the key role of the non-bone effects. *J Neuroeng Rehabil* 17: v50. doi: 10.1186/1743-0003-7-50.
22. Takata S (2015) Active vitamin D3 analog. *Nihon Rinsho* 73: 1701-1705.
23. Saito K, Miyakoshi N, Matsunaga T, et al. (2016) Eldecalcitol improves muscle strength and dynamic balance in postmenopausal women with osteoporosis: an open-label randomized controlled study. *J Bone Miner Metab* 34: 547-554.

24. Wihlborg A, Englund M, Åkesson K, et al. (2015) Fracture predictive ability of physical performance tests and history of falls in elderly women: a 10-year prospective study. *Osteoporos Int* 26: 2101-2109. doi: 10.1007/s00198-015-3106-1.
25. Bird ML, Hill KD, Robertson I, et al. (2013) The association between seasonal variation in vitamin d, postural sway, and falls risk: an observational cohort study. *J Aging Res* 2013:751310. doi: 10.1155/2013/751310.
26. Matheï C, Van Pottelbergh G, Vaes B, et al. (2013) No relation between vitamin D status and physical performance in the oldest old: results from the Belfrail study. *Age Ageing* 42: 186-190. doi: 10.1093/ageing/afs186.
27. Boersma D, Demontiero O, Mohtasham Amiri Z, et al. (2012) Vitamin D status in relation to postural stability in the elderly. *J Nutr Health Aging* 16: 270-275.
28. Krause M, Anschütz W, Vettorazzi E, et al. (2014) Vitamin D deficiency intensifies deterioration of risk factors, such as male sex and absence of vision, leading to increased postural body sway. *Gait Posture* 39: 166-171. doi: 10.1016/j.gaitpost.2013.06.017.
29. Akdeniz S, Hepguler S, Öztürk C, et al. (2016) The relation between vitamin D and postural balance according to clinical tests and tetrax posturography. *J Phys Ther Sci* 28: 1272-1277. doi: 10.1589/jpts.28.1272.
30. Sanyelbhaa H, Sanyelbhaa A (2015) Vestibular-evoked myogenic potentials and subjective visual vertical testing in patients with vitamin D deficiency/insufficiency. *Eur Arch Otorhinolaryngol* 272: 3233-329. doi: 10.1007/s00405-014-3395-6.
31. Menant JC, Close JC, Delbaere K, et al. (2012) Relationships between serum vitamin D levels, neuromuscular and neuropsychological function and falls in older men and women. *Osteoporos Int* 23: 981-989. doi: 10.1007/s00198-011-1637-7.
32. Uusi-Rasi K, Patil R, Karinkanta S, et al. (2015) Exercise and vitamin D in fall prevention among older women: a randomized clinical trial. JAMA *Intern Med* 175: 703-711. doi:10.1001/jamainternmed.2015.0225.
33. Anek A, Bunyaratavej N, Jittivilai T (2015) Effects of short-term vitamin D supplementation on musculoskeletal and body balance for prevention of falling in postmenopausal women. *J Med Assoc Thai* 98 Suppl 8: S26-31.
34. Cangussu LM, Nahas-Neto J, Orsatti CL, et al. (2016) Effect of isolated vitamin D supplementation on the rate of falls and postural balance in postmenopausal women fallers: a randomized, double-blind, placebo-controlled trial. *Menopause* 23: 267-274. doi: 10.1097/GME.0000000000000525.
35. Tellioglu A, Basaran S, Guzel R, et al. (2012) Efficacy and safety of high dose intramuscular or oral cholecalciferol in vitamin D deficient/insufficient elderly. *Maturitas* 72: 332-338. doi: 10.1016/j.maturitas.2012.04.011.
36. Perin A, Zanatta E, Pigatto E, et al. (2012) Hypovitaminosis D in an hospitalized old population of Western Friuli. *Reumatismo* 64: 166-171. doi: 10.4081/reumatismo.2012.166.

37. Kirn DR, Koochek A, Reid KF, et al. (2015) The Vitality, Independence, and Vigor in the Elderly 2 Study (VIVE2): design and methods. *Contemp Clin Trials* 43: 164-171. doi:10.1016/j.cct.2015.06.001.
38. Schacht E, Ringe JD (2012) Alfacalcidol improves muscle power, muscle function and balance in elderly patients with reduced bone mass. *Rheumatol Int* 32: 207-215. doi: 10.1007/s00296-010-1607-y.
39. Lips P, Binkley N, Pfeifer M, et al. (2010) Once-weekly dose of 8400 IU vitamin D(3) compared with placebo: effects on neuromuscular function and tolerability in older adults with vitamin D insufficiency. *Am J Clin Nutr* 91: 985-991. doi: 10.3945/ajcn.2009.28113.
40. Rizzoli R, Boonen S, Brandi ML, et al. (2013) Vitamin D supplementation in elderly or postmenopausal women: a 2013 update of the 2008 recommendations from the European Society for Clinical and Economic Aspects of Osteoporosis and Osteoarthritis (ESCEO). *Curr Med Res Opin* 29: 305-313. doi: 10.1185/03007995.2013.766162.
41. Dhesi JK, Jackson SH, Bearne LM, et al. (2004) Vitamin D supplementation improves neuromuscular function in older people who fall. *Age Ageing* 33: 589-595.
42. LeBlanc E, Chou R, Zakher B, et al. (2014) Screening for Vitamin D deficiency: systematic review for the U.S. Preventive Services Task Force Recommendation [Internet]. Rockville (MD): Agency for Healthcare Research and Quality (US); Available from http://www.ncbi.nlm.nih.gov/books/NBK263419/.
43. Dawson-Hughes B (2012) Serum 25-hydroxyvitamin D and muscle atrophy in the elderly. *Proc Nutr Soc* 71: 46-49. doi: 10.1017/S0029665111003260.
44. Dhesi JK, Bearne LM, Moniz C, et al. (2002). Neuromuscular and psychomotor function in elderly subjects who fall and the relationship with vitamin D status. *J Bone Min Res* 17: 891-897.
45. Nakamura K, Oshiki R, Hatakeyama K, et al. (2006). Vitamin D status, postural sway, and the incidence of falls in elderly community-dwelling Japanese women. *Arch Osteoporosis* 1: 21-27.
46. Fujita T, Nakamura S, Ohue M, et al. (2007) Postural stabilizing effect of alfacalcidol algal calcium (AAA Ca) compared with calcium carbonate assessed by computerized posturography. *J Bone Miner Metab* 25: 68-73.

AIMS Press