Serum [25(OH)D] status, ankle strength and activity show seasonal variation in older adults: relevance for winter falls in higher latitudes

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Abstract

Background: seasonal variation exists in serum [25(OH)D] and physical activity, especially at higher latitudes, and these factors impact lower limb strength. This study investigates seasonal variation in leg strength in a longitudinal repeated measures design concurrently with serum vitamin D and physical activity.

Methods: eighty-eight community-dwelling independently mobile older adults (69.2 ± 6.5 years) were evaluated five times over a year, at the end of five consecutive seasons at latitude 41.1°S, recruited in two cohorts. Leg strength, serum [25(OH)D] and physical activity levels were measured. Time spent outside was recorded. Monthly falls diaries recorded falls. Data were analysed to determine annual means and percentage changes.

Results: significant variation in [25(OH)D] (±15%), physical activity (±13%), ankle dorsiflexor strength (±8%) and hours spent outside (±20%) (all \(P < 0.001\)) was demonstrated over the year, with maximums in January and February (mid-summer). Low mean ankle strength was associated with increased incidence of falling (\(P = 0.047\)). Quadriceps strength did not change (±2%; \(P = 0.53\)).

Conclusion: ankle dorsiflexor strength varied seasonally. Increased ankle strength in summer may be influenced by increased levels of outdoors activity over the summer months. Reduced winter-time dorsiflexor strength may predispose older people to increased risk of tripping-related falls, and warrants investigation in a multi-faceted falls prevention programme.

Keywords: elderly, exercise, preventative measures, physical activity, accidental falls

Introduction

Serum 25 hydroxyvitamin D [25(OH)D] concentrations bear an inverse relationship to increased fracture rates from falls in older adults in the winter months [1]. While some of this effect is likely due to transient changes within the bone architecture, lower [25(OH)D] levels also affect muscle sarcopenia in older adults [2] and hence fall risk, with serum [25(OH)D] of <60 nmol/l associated with an increase in the risk of falling [3]. During the winter season, people reduce their physical activity, particularly outdoor activity [4], which may lead to further reductions in lower limb strength, although seasonal variation in muscle strength has not been investigated. A recent meta-analysis reported lower limb weakness to have an odds ratio of 1.76 for a single fall and 3.06 for multiple falling, and it is an important fall risk factor in older adults in a variety of environmental contexts [5].

It is important that people providing exercise interventions designed to reduce fall risk, or researchers who are drawing conclusions about the effectiveness of research interventions performed at various times of the year, are aware of any temporal variation in muscle strength, seasonal or otherwise. The present study was designed to determine whether muscle strength varies over the year, and if so, to determine the relationship between muscle strength and the timing of changes in [25(OH)D] status and levels of physical activity.
Levels of [25(OH)D] depend primarily on cutaneous manufacture of 25-hydroxy D₃ form, which occurs during direct exposure to Ultraviolet B radiation (UVB). At higher latitudes insufficient environmental UVB during winter can result in suboptimal or deficient [25(OH)D] status. In animal models, [25(OH)D] has an identified role in de novo protein synthesis [6], and severe [25(OH)D] deficiency is known to produce myopathy at serum levels of <25 nmol/l [7]. However, the relationship between insufficient/deficient levels of [25(OH)D] (25–75 nmol/l) and muscle strength is less clear [8, 9]. Differing results reported in these studies appear to depend on several factors, including the baseline level of [25(OH)D] of the participants [10]. The impact of supplementation on muscle strength depends on the length of follow-up, with changes in [25(OH)D] levels being evident sooner and muscle strength changes taking longer to become evident [11].

The amount of physical activity that older adults perform varies with the seasons, with men over 60 years expending an average additional 1.4 (95% CI: 0.4–2.3) metabolic equivalent units (MET) h/day (an increase of approximately 35%) and 1.0 (95% CI: 0.3–1.7) MET for women during summer compared with the winter season [12]. This holds true in older adults regardless of fitness status [13] and appears to be associated with an increase in the number of different activities performed [14].

A higher incidence of falling in winter has been related to lower air temperatures [15], and the rate of fractures from injurious falls has been shown to increase at the end of the winter season [1]. More hip fractures occur in colder months, with ambient temperature associated most closely with injury, while prevailing levels of precipitation are less important, as many falls that result in fractures occur within the home [16]. Despite this, evidence exists for an increase in falls that result from injuries within the home [17]. Risk factors for indoors and outdoors falls are different [18], and it may be that different populations (in terms of frailty) are also a factor to consider when reviewing the fall venue. A higher proportion of winter fallers had lower limb weakness compared with fallers in summer and spring seasons [15].

Recent population studies investigating the status of [25(OH)D] have used large cohorts, measured at different times of the year (with each person only measured once) to estimate the population means at those times [1, 19]. In contrast, this study uses a longitudinal design to measure a variety of variables on each participant over five time points.

This paper tests the hypothesis that higher muscle strength will be seen in summer and that this will be associated with higher levels of serum [25(OH)D] and higher physical activity.

**Methods**

For the methods section, please see Supplementary data (Appendix 1) available at *Age and Ageing* online.

**Results**

Ninety-eight participants enrolled in this study. Eighty-eight people were included in the final analysis. Two people did not attend appointments, three suffered adverse medical events (neurological and cardiovascular), and three were overseas at testing times. Two participants attended testing, but were not able to perform the physical tests due to musculoskeletal pain (knee osteoarthritis). Sixty-two per cent of participants reported one or more chronic health conditions; the commonest of these being hypertension (30%), arthritis (14%) and cardiovascular disease (9%). All participants were living independently and mobile. Characteristics for participants who completed the study are reported in Table 1.

Significant seasonal variations were observed in ankle dorsiﬂexor strength, serum [25(OH)D], physical activity and time spent outside (all \(P < 0.001\)), with the highest values observed in summer. No seasonal change was noted in quadriceps strength. Table 2 presents baseline data for participants for these variables, as well as mean annual value (mesor) and amplitude of seasonal change in mesor, with 95% CI. The peak value for serum [25(OH)D] levels was seen 4 weeks after the peaks in the other variables, with no significant difference in the timing between ankle strength, activity and sun exposure (Figure 1).

Ankle dorsiﬂexor strength showed significant \((P < 0.001)\) variation across the year, with the highest value seen in mid-summer (January in southern hemisphere) and the magnitude of the variation at 8% (95% CI: 6–11%). Quadriceps strength did not vary over the year, \((P = 0.53)\). To explore these effects, regression analysis was undertaken for age and season that showed significant association between changes in ankle strength and knee strength \((0.2 \text{ kg}/1 \text{ SD of } \text{knee strength}, 95\% \text{ CI: } 0.17–0.29; \, P < 0.01)\). Ankle strength was associated with physical activity \((mean 0.38 \text{ kg}/1 \text{ SD of CHAMPS}; 95\% \text{ CI: } 0.05–0.72; \, P = 0.026)\), ankle strength and sun exposure \((mean 0.34 \text{ kg}/1 \text{ SD of sun exposure}; 95\% \text{ CI: } 0.07–0.2; \, P = 0.014)\). Knee strength was only associated with physical activity \((mean 0.02 \text{ kg}/1 \text{ SD of CHAMPS}; 95\% \text{ CI: } 0.00–0.08; \, P = 0.026)\).

**Table 1.** Characteristics of participants at entry into the study (visit 1)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (SD)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>69.2 (6.5)</td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>74.6 (12.0)</td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>165 (8.9)</td>
<td></td>
</tr>
<tr>
<td>Living alone</td>
<td>8 out of 81</td>
<td></td>
</tr>
<tr>
<td>% in full time work</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>% with chronic health conditions</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>% men</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>% more than four medications</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>% taking statin medication</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>% taking psychotropic medication</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>
95% CI: 0.004–0.03; \(P = 0.012\). Neither ankle strength \((P = 0.16)\) nor knee strength \((P = 0.69)\) was associated with serum \([25(OH)D]\). Low ankle strength was associated with increased incidence of falling (mean −0.004 falls/1 SD of ankle strength, 95% CI: −0.007 to 0; \(P = 0.047\)).

Compliance with completing the falls diaries was 100%. Seventy-five per cent of fall diaries were posted on schedule while the remaining diaries were returned at the subsequent assessment appointment. In total, 48 falls were experienced by the cohort (54 falls/hundred person-years). Seasonally, most falls occurred in winter/autumn (30 falls; 34 falls/hundred person-years).

The magnitude of the seasonal variation in serum \([25(OH)D]\) was 15%, with the highest values seen at the end of summer \((P < 0.001)\) [group mean peak on 27 February (95% CI: 19 February to 7 March)]. Seventeen per cent of the participants used supplementation of <800 IU/day, coinciding with the peak in ankle strength. Activity and sun exposure showed a moderate association (\(r = 0.4\), \(P < 0.001\)).

### Discussion

This study demonstrates moderate seasonal variations in ankle muscle strength, serum \([25(OH)D]\) levels and physical activity, with the peak and troughs in serum \([25(OH)D]\) levels occurring over 1 month after the peak and troughs in the other measures. Increased ankle strength is associated with increased activity and time spent outside. Low mean ankle strength showed an association with fall incidence.

The greatest values for ankle strength occurred in summer, coinciding with the highest values for physical activity. The lowest levels of ankle strength and activity were recorded in winter, with a 13% reduction in physical activity seen simultaneously with an 8% significant reduction in ankle strength. Reductions in ankle strength observed in the winter months may be important contributors to trip-related falls. Up to 53% of falls in a similarly aged community-dwelling group were found to be as a result of tripping [20]. For older adults who are less active outside in

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**Table 2. Performance of participants at vists 1-5, mesor (annual mean value) and amplitude of seasonal change**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (SD) End of Winter September (n = 20)</th>
<th>Mean (SD) End of Spring December (n = 88)</th>
<th>Mean (SD) End of Summer March (n = 88)</th>
<th>Mean (SD) End of Autumn June (n = 88)</th>
<th>Mean (SD) End of Winter September (n = 88)</th>
<th>Mean (SD) End of Spring December (n = 68)</th>
<th>Mesor Amplitude of seasonal change mean (95%CI)(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankle Strength (Kg)</td>
<td>8.6 (4.1)</td>
<td>11.7 (3.9)</td>
<td>10.6 (4.0)</td>
<td>9.3 (3.7)</td>
<td>9.9 (3.5)</td>
<td>10.1 (3.9)</td>
<td>10.1 (2.7)</td>
</tr>
<tr>
<td>Knee Strength (Kg)</td>
<td>17.6 (5.5)</td>
<td>20.4 (8.0)</td>
<td>19.7 (7.6)</td>
<td>18.8 (5.7)</td>
<td>19.3 (6.9)</td>
<td>18.5 (6.5)</td>
<td>19.2 (4.7)</td>
</tr>
<tr>
<td>Vitamin D (nmol/L)</td>
<td>46.8 (16.4)</td>
<td>59.1 (18.0)</td>
<td>68.1 (20.6)</td>
<td>58.1 (21.2)</td>
<td>51.9 (20.9)</td>
<td>58.7 (20.1)</td>
<td>59.2 (18.2)</td>
</tr>
<tr>
<td>Activity (MET Hours/week)</td>
<td>55.8 (55.1)</td>
<td>55.4 (33.9)</td>
<td>55.2 (36.1)</td>
<td>44.4 (29.4)</td>
<td>45.1 (30.3)</td>
<td>47.9 (27.8)</td>
<td>50.0 (25.8)</td>
</tr>
<tr>
<td>Sun Exposure (hours)</td>
<td>n/a</td>
<td>6.4 (3.4)</td>
<td>6.3 (3.4)</td>
<td>5.6 (3.2)</td>
<td>5.4 (3.5)</td>
<td>7.9 (2.9)</td>
<td>6.2 (2.4)</td>
</tr>
</tbody>
</table>

\(^a\)Estimated by repeated measures non-linear regression (mean and 95% confidence intervals), adjusted for age, gender and starting cohort.

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**Figure 1.** Seasonal variation in \([25(OH)D]\), ankle and knee strength, activity (CHAMPS) and time spent outside (sun). Data presented as percentage change around mesor (expressed as 100%). Mesor is annual mean value. The sine wave represents an interpolation of the non-linear model using a sine wave formula of data collected in five (3 week) time windows (Sep, Dec, Mar, June, Sep, Dec).
the winter months, due to poor weather conditions or limited daylight hours, the benefits of activities to improve dorsiflexion strength could be usefully investigated. A recent large randomised trial incorporating foot and ankle exercise as part of a multi-faceted podiatric intervention increased ankle muscle strength (particularly inversion) and reduced falls [21]. Values for ankle dorsiflexion strength changes in that study also approached significance \( P = 0.063 \) with concurrent improvements in balance [21]. Data from the current study found a significant association between mean ankle strength and fall incidence, albeit of a small magnitude, likely due to the low number of falls recorded over the duration of the study. The clinical significance of the 8% change in dorsiflexion strength in the current study is difficult to quantify, but a 16% improvement in this parameter post-resistance training was shown to concurrently occur with a decrease in fall risk of 57.3% [22].

Lower limb strength is one of the most important fall risk factors in older adults [23]. The temporal stability of knee strength found in this study has good implications for fall risk throughout the year in this cohort. The fact that the quadriceps and tibialis anterior muscles behave differently over the year in terms of strength changes, suggest that year-round incidental activities (sit-to-stand, routine home activities such as cleaning, gardening, shopping and climbing stairs) that place a moderate demand on proximal muscles such as hip and knee extensors, may have a greater effect on preserving proximal muscle strength than ankle muscle strength through winter, irrespective of serum [25(OH)D] status. As the peak for serum [25(OH)D] levels occurs over a month after the peak for muscle strength, sufficient levels to maximise ankle strength may have been reached prior to its peak, so that additional increases may not have any additional effect on strength measures.

The older adults who participated in the current study were 13% more active during the summer months, increasing their activity by an average of 1.3 MET h/day in January compared with August. Concurrently, ankle strength was also increased, although no causality can be inferred by this association. Evidence is growing to indicate that physical activity is important in maintaining physical function and mobility by impacting both muscle strength and balance in older adults, with some authors suggesting the positive sequellae of this may be fall prevention [24]. In our study, participants increased activity levels in summer months, when longer daylight hours and warmer weather provide greater opportunities for activity outdoors.

Limitations

This study was performed in a group of community-dwelling older adults, physically capable of changing their outside activity levels in response to positive and negative environmental factors. Thus the results are not generalisable to other older adults, particularly those who are institutionalised or frail and less likely to vary the time they spend outside. These data were collected at a latitude of 41 degrees south, and the seasonal differences observed here may not be the same at different latitudes. Dietary consumption of vitamin D and skin protection behaviours in modifying UVB absorption may be important contributors to serum [25(OH)D] status and will be considered in future publications.

Conclusion

Ankle strength varied seasonally, with lower levels seen in winter months, and lower mean ankle strength was associated with an increased risk of falling. For clinicians and researchers who provide interventions designed to improve leg strength, this research provides evidence of clear seasonal variation in ankle dorsiflexion strength that needs to be considered when measuring strength changes as part of any intervention. The reduced ankle dorsiflexor strength in winter months may predispose older people to an increased risk of tripping-related falls, which may warrant investigation as part of a multi-faceted falls prevention programme.

Key points

- Ankle strength shows natural annual variation in older adults.
- Knee extension strength does not show annual variation.
- Seasonal strength changes provide implications for researchers and clinicians providing long-term exercise interventions.

Conflicts of interest

None declared.

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Supplementary data

Supplementary data mentioned in the text is available to subscribers in *Age and Ageing* online.

References

Seasonal serum [25(OH)D] strength and activity


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