Patient level pooled analysis of 68,500 patients from seven major vitamin D fracture trials in the US and Europe


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Patient level pooled analysis of 68 500 patients from seven major vitamin D fracture trials in US and Europe

The DIPART (vitamin D Individual Patient Analysis of Randomized Trials) Group

ABSTRACT

Objectives To identify participants’ characteristics that influence the anti-fracture efficacy of vitamin D or vitamin D plus calcium with respect to any fracture, hip fracture, and clinical vertebral fracture and to assess the influence of dosing regimens and co-administration of calcium.

Design Individual patient data analysis using pooled data from randomised trials.

Data sources Seven major randomised trials of vitamin D with calcium or vitamin D alone, yielding a total of 68 517 participants (mean age 69.9 years, range 47-107 years, 14.7% men).

Study selection Studies included were randomised studies with at least one intervention arm in which vitamin D was given, fracture as an outcome, and at least 1000 participants.

Data synthesis Logistic regression analysis was used to identify significant interaction terms, followed by Cox’s proportional hazards models incorporating age, sex, fracture history, and hormone therapy and bisphosphonate use.

Results Trials using vitamin D with calcium showed a reduced overall risk of fracture (hazard ratio 0.92, 95% confidence interval 0.86 to 0.99, P=0.025) and hip fracture (all studies: 0.84, 0.70 to 1.01, P=0.07; studies using 10 μg of vitamin D given with calcium: 0.74, 0.60 to 0.91, P=0.005). For vitamin D alone in daily doses of 10 μg or 20 μg, no significant effects were found. No interaction was found between fracture history and treatment response, nor any interaction with age, sex, or hormone replacement therapy.

Conclusion This individual patient data analysis indicates that vitamin D given alone in doses of 10-20 μg is not effective in preventing fractures. By contrast, calcium and vitamin D given together reduce hip fractures and total fractures, and probably vertebral fractures, irrespective of age, sex, or previous fractures.

INTRODUCTION

Fragility fractures cause excess mortality, substantial morbidity, and related health and social service expenditures in older people. Risk of fracture is higher in institutionalised older people than in community dwelling older people of the same age, reflecting a greater risk of falls and lower bone mineral density. Vitamin D insufficiency is common in older people, particularly in residential and care homes. This may contribute to secondary hyperparathyroidism, bone loss, impaired neuromuscular function, and an increased risk of falls and fractures. This provides the rationale for using vitamin D to prevent fractures in older people.

A large randomised controlled trial in women in French nursing homes or apartments for older people showed that calcium and vitamin D supplementation increased serum 25-hydroxyvitamin D, decreased parathyroid hormone, improved bone density, and decreased hip fractures and other non-vertebral fractures. Subsequent randomised trials examining the effect of vitamin D supplementation—with or without calcium—on the incidence of fractures have produced conflicting results. A meta-analysis in 2005 suggested that 17.5-20 μg of vitamin D daily decreased the risk of hip and non-vertebral fractures, whereas lower doses (10 μg/day) were ineffective. However, recent meta-analyses indicate that a combination of calcium and vitamin D reduces hip and non-vertebral fractures but that vitamin D alone does not.

Study level meta-analyses may be adequate when estimating a singled pooled treatment effect or investigating study level characteristics, but they can lead to biased assessments and have limitations in explaining heterogeneity. Analyses of individual patients’ data offer improved statistical power to investigate whether treatment effects are related to the patient. We used individual patient data methods to do a meta-analysis of randomised controlled trials of vitamin D—with or without calcium—in preventing fractures and investigated if treatment effects are influenced by patients’ characteristics.

METHODS

Searching and selection criteria

We searched, with no language restrictions, for publications between January 1966 and July 2008 in Medline, Embase, and the Cochrane Central Register of Controlled Trials by using MeSH terms: [Fractures, bone] combined with [Vitamin D], [Ergocalciferol] or [Cholecalciferol]. We also searched for text words in title and abstract: “Fractu” or “Bone fractu”, in combination with “Vitamin D”, “Cholecalciferol”, or “Colecalciferol”. We included studies if they were
randomised (individual or cluster), had at least one intervention arm in which vitamin D was given and one arm without vitamin D, used fracture as an outcome, and included at least 1000 patients. The decision to include only studies above this size was driven by concerns that each study, while contributing additional cases, would also further reduce the mass of shared study variables for aggregated analysis. We identified 248 abstracts (fig 1); 47 covered clinical trials of vitamin D with a fracture outcome—36 with n<1000 and 11 with n≥1000. We contacted the corresponding authors of these 11 trials. Four groups were unwilling or unable to provide patient level data.9-17 Seven groups agreed to participate.

Included studies
Six studies were individually randomised.18-23 One study was cluster randomised at the level of home care district.24 Of the individually randomised controlled trials, one was quasi-randomised by birth date.19 Two studies used a factorial design.22,24 Table 1 gives the details of the studies. Information on fracture history was not available in one study.18 All studies reported incident hip fractures and other non-vertebral fractures. All but one reported on clinical vertebral fractures.19

Data extraction and validation
We defined a standardised data format and retrieved datasets electronically in anonymised form from the corresponding authors. We issued queries to the participating centres for discordant data.

Quantitative data synthesis and statistical analysis
We analysed data at the level of the patient and according to the intention to treat principle. The timescale used was number of days between date of randomisation and date of fracture. When the fracture date was unknown, we used the date of the reporting visit. The primary end point was any fracture, with hip fracture and clinical vertebral fracture as secondary end points. We defined base models by using conditional logistic regression incorporating known predictors of fracture risk, which would be expected a priori to contribute to variation in fracture rates: age, sex, hormone replacement therapy, bisphosphonates, previous hip fracture, previous vertebral fracture, and “other previous fracture” in adulthood. We added treatment allocation and interaction terms to this model to identify factors that significantly modified the response to vitamin D. We pre-specified the following study level variables for entry into this interaction analysis: vitamin D daily dose equivalent, route (oral or intramuscular), and co-administration of calcium. We then used variables that interacted significantly to stratify the subsequent fixed effects Cox fracture-free survival analysis, which contained a series of dummy variables to capture residual differences in risk of fracture between trials. A subgroup analysis by dose (10 μg/day ± 20 μg/day) was pre-specified. We thus classified the Meyer, Larsen, and Women’s Health Initiative (WHI) studies as 10 μg studies and classified the Smith study (equivalent to 20.5 μg/day), the Lyons study, the RECORD study, and the Porthouse study (all equivalent to 20 μg/day) as 20 μg studies. Observations were truncated after 36 months; only the WHI study provided sufficient patients to populate the analysis beyond this.

Sensitivity
We did an influence analysis to assess to what extent conclusions would have been modified by failure to include one or more individual studies in the analysis. Recent work suggests that ergocalciferol has half the calcitrophic effect of cholecalciferol,25 so we regrouped 20 μg ergocalciferol studies with 10 μg cholecalciferol studies.

RESULTS
Base model including previous fractures (six studies, n=65,073)
Increasing age (hazard ratio per decade 1.34, 95% confidence interval 1.29 to 1.39), male sex (0.52, 0.47 to 0.58), previous hip fracture (1.86, 1.62 to 2.14), previous vertebral fracture (1.71, 1.31 to 2.22), other fracture (1.45, 1.35 to 1.57), baseline bisphosphonate use (1.54, 1.22 to 1.92), and baseline hormone replacement therapy (0.69, 0.63 to 0.76) contributed significantly to the risk of any fracture. Strongly statistically significant interaction terms were route of vitamin D administration (P=0.02), dosing interval (P=0.02), and co-administration of calcium (P=0.006), indicating significant modification of response to treatment (fig 2). Bisphosphonate use was of borderline significance (P=0.07). Previous fractures did not significantly interact with treatment response (P=0.64 to 0.79 depending on site), nor did we find an interaction with age, sex, or hormone replacement therapy. As previous fractures did not modify the response, we included the Lyons study, which had no information on previous fractures, in the analysis.

![Flow chart of analysis. RCT=randomised controlled trial](https://example.com/flowchart.png)
Table 1 | Characteristics of seven included clinical trials

<table>
<thead>
<tr>
<th>Trial</th>
<th>Patient category</th>
<th>Randomisation* and duration</th>
<th>Study arms</th>
<th>No</th>
<th>Mean (range) age</th>
<th>Men (%)</th>
<th>Previous fracture (%)</th>
<th>Hormone therapy and bisphosphonates allowed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lyons18</td>
<td>Residential home or sheltered housing residents (UK)</td>
<td>I; 36 months</td>
<td>Oral D3 100 000 IU/4 months v placebo</td>
<td>3440</td>
<td>83.8 (62-107)</td>
<td>23.7</td>
<td>ND</td>
<td>Yes</td>
</tr>
<tr>
<td>Meyer19</td>
<td>Nursing home residents (Norway)</td>
<td>Q; 24 months</td>
<td>Oral D3 10 μg/day v placebo</td>
<td>1144</td>
<td>84.7 (47.6-101)</td>
<td>24.1</td>
<td>Hip 26.2; vertebral ND; other ND</td>
<td>Yes</td>
</tr>
<tr>
<td>Porthouse21</td>
<td>General practice patients with risk factors (UK)</td>
<td>I; 18-42 months (median 22.5)</td>
<td>Oral D3 20 μg/day + 1000 mg calcium v leaflet</td>
<td>3314</td>
<td>76.8 (70.2-102.7)</td>
<td>0</td>
<td>Hip 0.5; vertebral 0.8; other 56.5</td>
<td>Yes</td>
</tr>
<tr>
<td>Larsen24</td>
<td>Community dwelling age ≥66 (Denmark)</td>
<td>C; 42 months</td>
<td>Oral D3 10 μg/day + calcium 1000 mg + environmental intervention v oral D3 10 μg/day + calcium 1000 mg v environmental intervention v none</td>
<td>9605</td>
<td>75 (66-103)</td>
<td>39.9</td>
<td>Hip 3.3; vertebral 0.7; other 7.4</td>
<td>Yes</td>
</tr>
<tr>
<td>RECORD22</td>
<td>Previous osteoporotic fracture (UK)</td>
<td>I; up to 36 months (median 30.4)</td>
<td>Oral D3 20 μg/day + calcium 1000 mg v oral D3 20 μg/day v calcium 1000 mg v double placebo</td>
<td>5292</td>
<td>77.5 (70-100)</td>
<td>15.3</td>
<td>Hip 17.1; vertebral 0.2; other 82.8</td>
<td>No</td>
</tr>
<tr>
<td>Smith20</td>
<td>General practice patients presenting for influenza vaccination (UK)</td>
<td>I; median 85. 4 months</td>
<td>Intramuscular D3 300 000 IU/12 months v placebo</td>
<td>9440</td>
<td>80.2 (70.3-100.1)</td>
<td>46.1</td>
<td>Hip 2.8; vertebral 0.6; other 34.8</td>
<td>No</td>
</tr>
<tr>
<td>WHI23</td>
<td>Community based, postmenopausal women aged ≥50 (US)</td>
<td>I; median 85. 4 months</td>
<td>Oral D3 10 μg/day + calcium 1000 mg v placebo</td>
<td>36 282</td>
<td>62.4 (51-81)</td>
<td>None</td>
<td>Hip 0.6; vertebral 1.5; other 9.8</td>
<td>Yes</td>
</tr>
</tbody>
</table>

ND=not determined.

*Individually randomised; Q=quasi-randomised by birth date; C=cluster randomised.

Base model not including previous fractures (seven studies, n=68516)

Decade of age [hazard ratio 1.43, 1.38 to 1.48], male sex (0.51, 0.46 to 0.56), hormone replacement therapy (0.65, 0.60 to 0.72), and bisphosphonate use (1.56, 1.25 to 1.95) contributed significantly to the risk of any fracture. Significant interaction terms were route (P=0.03) and calcium (P=0.04), and borderline significant interaction terms were bisphosphate use (P=0.06) and interval (daily v non-daily, P=0.12).

Effect of vitamin D treatment (with or without calcium)

Any fracture

The analysis covered 7202 fractures over 177 203 person years. Placebo fracture rates were higher in the vitamin D trials than in the trials combining vitamin D with calcium, as these studies recruited older participants (table 1). We found no significant effect of vitamin D without calcium [hazard ratio 1.01, 0.92 to 1.12, P=0.80] (fig 3). Studies in which vitamin D was combined with calcium showed reduced fracture risk [hazard ratio 0.92, 0.86 to 0.99, P=0.025]. We adjusted the analysis for study, age, and sex, as well as for baseline hormone replacement and bisphosphonate use. Stratification by route of administration showed a significant effect of oral vitamin D [hazard ratio 0.93, 0.87 to 0.99, P=0.02] but not injected vitamin D [1.11, 0.95 to 1.31, P=0.20]. Results were unaffected by exclusion of users of hormone replacement therapy and bisphosphonates. We found no significant treatment by study interaction in either group of studies (calcium and vitamin D studies P=0.67 to 0.78, vitamin D studies P=0.14 to 0.44).

Hip fracture

In total, 978 hip fractures were recorded. The risk of hip fracture was borderline decreased by vitamin D with calcium [hazard ratio 0.84, 0.70 to 1.01, P=0.07] (fig 4). Vitamin D studies showed no reduction in risk of hip fracture [1.09, 0.92 to 1.29, P=0.34]. Rates of hip fracture in the placebo group were lower in the calcium and vitamin D trials than in the vitamin D studies. Stratification by route showed treatment effects short of statistical significance [oral studies 0.93, 0.81 to 1.06, P=0.26; intramuscular studies 1.46, 1.00 to 2.13, P=0.05]. We found borderline significant treatment by study interaction terms for the RECORD study (P=0.06) and the Lyons study (P=0.09). This was driven by a hazard ratio for hip fracture with vitamin D of 0.98 (0.76 to 1.27) in the Lyons study [pooled hazard ratio 1.18 (0.94 to 1.48) in the other vitamin D studies] and a hazard ratio of 1.31 in the RECORD study [pooled hazard ratio 0.76 (0.62 to 0.94) for the remaining calcium and vitamin D studies].

Clinical vertebral fracture

Only 542 incident clinical vertebral fractures were reported. We found no significant treatment effect in calcium and vitamin D studies [hazard ratio 0.85, 0.66 to 1.11, P=0.25] or vitamin D studies [1.12, 0.70 to 1.79, P=0.63] or when stratified by route of administration [P=0.27 to 0.29].

Vitamin D dose

Irrespective of site of fracture or dose of vitamin D, we found no significant effect of vitamin D given without
calcium. Vitamin D given as 10 μg with calcium significantly reduced the risk of any fracture (P<0.05) and hip fracture (P<0.01). However, the 20 μg dose with calcium was not associated with a reduced risk of fracture (P=0.58) (table 2).

**Absolute risk reduction and numbers needed to treat**

We did this analysis only for vitamin D given with calcium, as vitamin D given alone could not be shown to reduce fracture risk significantly. For any fracture, calcium with vitamin D was associated with an absolute risk reduction of 0.5% over three years (untreated event rate 21.0 per 1000 person years, hazard ratio 0.92), corresponding to a number needed to treat of 213 people treated for three years to prevent a fracture. For people over the age of 70, the absolute risk reduction was 0.9% (untreated event rate 29.0 per 1000 person years, hazard ratio 0.89) and the number needed to treat was 111. The corresponding numbers for people with previous fracture (untreated event rate 33.5 per 1000 person years, hazard ratio 0.87), irrespective of age, were 1.2% and 82. For hip fractures specifically, the absolute risk reduction was 0.4% for participants aged over 70 and 0.2% in participants with previous fractures, giving numbers needed to treat of 255 and 548.

**Sensitivity analysis**

In the influence analysis for vitamin D trials, the hazard ratio remained close to 1.0 irrespective of exclusion of any one study in both the any fracture scenario and the hip fracture scenario (fig 5). For calcium and vitamin D trials, the hip fracture analysis was sensitive to exclusion of contributing studies, leading to a mean effect close to 1.0 if the Larsen study was excluded. The corresponding any fracture analysis was robust, with mean hazard ratios indicating relatively little
Table 2 | Subanalysis* of anti-fracture efficacy, stratified by vitamin D dose and calcium co-administration

<table>
<thead>
<tr>
<th>Fracture</th>
<th>10 μg dose</th>
<th>20 μg dose</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(WHI, Larsen studies)</td>
<td>(Porthouse, RECORD-2 studies)</td>
</tr>
<tr>
<td>Any</td>
<td>Treated 18.7/1000 PY; untreated 20.2/1000 PY; HR=0.91 (95% CI 0.85 to 0.99), P=0.02</td>
<td>Treated 43.2/1000 PY; untreated 51.1/1000 PY; HR=0.95 (0.80 to 1.14), P=0.58</td>
</tr>
<tr>
<td>Hip</td>
<td>Treated 2.4/1000 PY; untreated 3.0/1000 PY; HR=0.74 (0.60 to 0.91), P=0.005</td>
<td>Treated 10.3/1000 PY; untreated 9.2/1000 PY; HR=1.30 (0.88 to 1.92), P=0.19</td>
</tr>
<tr>
<td>Vertebral</td>
<td>Treated 1.4/1000 PY; untreated 1.6/1000 PY; HR=0.86 (0.65 to 1.14), P=0.31</td>
<td>Treated 2.7/1000 PY; untreated 3.1/1000 PY; HR=0.97 (0.48 to 1.98), P=0.93</td>
</tr>
<tr>
<td>Without calcium:</td>
<td>(Meyer study)</td>
<td>(Lyons, Smith, RECORD-1 studies)</td>
</tr>
<tr>
<td>Any</td>
<td>Treated 85.9/1000 PY; untreated 94.1/1000 PY; HR=0.93 (0.67 to 1.28), P=0.64</td>
<td>Treated 45.9/1000 PY; untreated 44.4/1000 PY; HR=1.02 (0.92 to 1.14), P=0.69</td>
</tr>
<tr>
<td>Hip</td>
<td>Treated 61.3/1000 PY; untreated 56.2/1000 PY; HR=1.10 (0.74 to 1.64), P=0.64</td>
<td>Treated 14.0/1000 PY; untreated 13.0/1000 PY; HR=1.08 (0.89 to 1.30), P=0.45</td>
</tr>
<tr>
<td>Vertebral</td>
<td>NA</td>
<td>Treated 2.4/1000 PY; untreated 2.1/1000 PY; HR=1.10 (0.69 to 1.76), P=0.68</td>
</tr>
</tbody>
</table>

HR=hazard ratio; NA=not applicable; PY=person years.

*Cox proportional hazards model adjusted for patient level covariates of age, sex, study, and use of hormone replacement therapy and bisphosphonate.
Whether calcium is more important in preventing fractures than was previously recognised remains to be determined. An individual patient data meta-analysis is being done on this topic (Mark Bolland, personal communication, 2009). Calcium and vitamin D are likely to be more effective in attenuating secondary hyperparathyroidism, and thus bone turnover and bone loss, than is vitamin D alone. Higher doses of vitamin D than were used in the existing trials may be needed to suppress bone turnover if calcium is not co-administered. We did not have information related to baseline vitamin D (diet, sunlight, and supplements) and calcium intake. In most of the included studies, serum vitamin D was measured only in small subgroups. Wide variations are likely, owing to international differences in food fortification and differences in the age and mobility of study populations. Previous reports of protective effects of calcium and vitamin D supplementation in institutionalised populations and lack of effect in non-institutionalised populations suggest that such differences strongly modify the anti-fracture efficacy of calcium with vitamin D.

Within the vitamin D with calcium trials, only the lower vitamin D dose (10 μg daily) produced a reduction in hip fracture risk. This is not evidence that a 20 μg daily dose is inferior to a 10 μg daily dose but may reflect the fact that the trials of 20 μg vitamin D with calcium attempted to provide fracture prevention at a threefold higher risk level for hip fractures than did studies using the lower dose (table 2). Thus, our recommendation would be to use a vitamin D dose of at least 10 μg (400 IU) daily combined with 1000 mg of calcium. In high risk patients, this should be supplemented by bisphosphonates or other anti-osteoporotic drugs in accordance with national and international guidelines.

**Strengths and limitations**

We were unable to obtain data for four of the 11 identified studies that fulfilled the inclusion criteria. Our findings support and further substantiate previous meta-analyses of study level data that included these studies. The results of our analysis were robust in effect size and direction to the exclusion of very large contributing studies.

We restricted the analysis to 36 months, as only the WHI study was of materially longer duration. With our current knowledge on reversal of secondary hyperparathyroidism, this time frame seems reasonable.

The lack of anti-fracture efficacy seen in the Smith trial has been suggested to be due to low bioavailability of the preparation. However, although removing this study from the analysis (fig 5) nominally changed the anti-fracture effect of the vitamin D only studies from a small increase to a small decrease in risk, both results failed to achieve statistical significance.

We could not obtain sufficient information about compliance to do a per protocol analysis. The effect size should thus be considered as worst case. We had, however, pre-specified an intention to treat analysis as the primary hypothesis test for this study, allowing the effect size of this intervention to be compared with the effect sizes of interventions such as prevention of falls and anti-resorptive drugs.

The Larsen trial was very influential in the analysis for hip fracture but differed greatly from other studies in design by being randomised only at the level of home care districts and by using a factorial design by being randomised only at the level of home care districts and by using a factorial design by being randomised only at the level of home care districts and by using a factorial design by being randomised only at the level of home care districts and by using a factorial design by being randomised only at the level of home care districts and by using a factorial design. However, removing this study from the analysis (fig 5) nominally changed the anti-fracture effect of the vitamin D only studies from a small increase to a small decrease in risk, both results failed to achieve statistical significance.

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**Table 5** Sensitivity analysis: influence of removing individual studies from analysis. CaD = calcium and vitamin D trials; D = vitamin D trials; w/o = without.
WHAT IS ALREADY KNOWN ON THIS TOPIC
A rationale exists for the use of vitamin D to prevent fractures in older people
What dose of vitamin D is needed for prevention of fractures is unclear, as is whether daily
calcium co-supplementation is needed

WHAT THIS STUDY ADDS
Vitamin D alone in doses equivalent to 10-20 µg/day is not effective in fracture prevention
Co-administration of 1000 mg calcium/day is required for fracture prevention
Fracture prevention is found across a wide age range, irrespective of sex and fracture history
can be equated with an average daily dose for vitamin D remains unresolved. Additional studies would be
needed to clarify whether the failure of standalone vita-
mnin D in preventing fractures is due to the route of
administration, the long time interval between doses,
the nature of the vitamin D preparation, or the propen-
sity for studies of vitamin D to enrol participants of
higher age and greater fracture risk than do studies of
calcium and vitamin D. Although our analysis did not
provide support for any interaction with age or fracture
history, we cannot distinguish between effects of com-
 pound, route, and regimen, as studies of intramuscular
administration never used daily dosing, whereas cal-
cium and vitamin D studies always used oral adminis-
tration and invariably used daily dosing.

We had to make allowance for differences between
studies in available parameters—for example, no data on
fracture history were available in the Lyons study,19
and no data on incident clinical vertebral fractures
were available in the Meyer study.18 We saw no inter-
action, however, between treatment effect and fracture
history in six studies with available data. Studying
adverse events was beyond the scope of this analysis
and would have been difficult to interpret, as the
method of tracking differed more widely between stu-
dies than did reporting of fracture outcomes.

The important strength of this analysis is that we
were able to calculate absolute fracture rates and treat-
ment effects across a wide range of study participants and
interventions, adjust effects for previous fractures and
for the use of bisphosphonates and hormone replacement therapy at the level of the individual par-
ticipant, account for interactions and study heteroge-
enity, and further substantiate the conclusions of non-
individual patient data meta-analyses.

Conclusions and policy implications
Daily calcium and vitamin D supplementation, even at
doses as low as 10 µg of vitamin D daily, significantly
reduces the risk of fracture, with incidence curves
deviating after about 16 months. Fracture prevention
seemed to be homogeneous across a wide age range
and was unmodified by fracture history or sex. We
must emphasise that this analysis does not allow for a
direct comparison of vitamin D against vitamin D
given with calcium, but only comparisons between
each intervention and no treatment. Whether inter-
mittent doses of vitamin D given without calcium
supplements can reduce the risk of fractures remains
unresolved from the studies in this analysis. Additional
studies of vitamin D are also needed, especially trials of
vitamin D given daily at higher doses without calcium.

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LR, JWW, KB, JAR, LM, and RMF drafted the article. All members of the
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