REVIEW

Eldecalcitol for the treatment of osteoporosis

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Abstract: Eldecalcitol (1α, 25-dihydroxy-2β-[3-hydroxypropyloxy] vitamin D$_3$; ED-71) is a new analog of the active form of vitamin D. Eldecalcitol has recently been approved for the treatment of osteoporosis in Japan. In addition to regulation of calcium metabolism carried out by conventional vitamin D analogs, eldecalcitol possesses a strong inhibitory effect on bone resorption and causes a significant increase in bone mineral density. A Phase III clinical trial on osteoporosis showed that eldecalcitol reduced the incidence of new vertebral fractures over 3 years by 26% compared with alfacalcidol. Although the overall risk of nonvertebral fractures was not reduced by eldecalcitol, the risk of wrist fracture was decreased significantly in the eldecalcitol group (71%) compared with the alfacalcidol group. The serum level of 25-hydroxyvitamin D (25[OH]D) was normalized by supplementation of native vitamin D in this trial, so the desirable effects on bone by eldecalcitol were considered to be derived from its distinctive pharmacological action. Increased blood calcium was observed in 21% of patients treated with eldecalcitol, and hypercalcemia (>11.5 mg/dL) occurred in 0.4% of eldecalcitol recipients, so serum calcium concentration should be monitored after starting eldecalcitol treatment. Eldecalcitol has dual effects on the metabolism of bone and calcium and is useful for the treatment of osteoporosis, especially for elderly patients (who frequently suffer from vitamin D deficiency). This article reviews the clinical efficacy and safety of eldecalcitol in the treatment of osteoporosis.

Keywords: vitamin D, osteoporosis, bone mineral density, nonvertebral fracture

Introduction

Osteoporosis is a systemic skeletal disease associated with low bone mass and microarchitectural deterioration of bone tissue, with a consequent increase in bone fragility and fracture risk.[1] Osteoporosis-related fractures occur commonly in the spine, hip and distal radius. These fractures impact negatively on quality of life and increase morbidity and mortality.[2,3] Treatment of osteoporosis is important for preventing osteoporotic fractures and reducing the health care burden.

Vitamin D is a crucial factor for the intestinal absorption of calcium to maintain bone strength. A deficiency in vitamin D causes impaired absorption of calcium and bone mineralization, leading to rickets in children and osteomalacia in adults.[4–6] The elderly are at risk of a deficiency and an insufficiency of vitamin D because of their reduced mobility and consequent decreased exposure to sunshine, a low food intake, and decline in renal function.[4,7] Vitamin D insufficiency causes greater secretion of parathyroid hormone (PTH) due to the low serum levels of calcium and active vitamin D, resulting in high bone turnover and increased bone resorption. Vitamin D insufficiency is also associated with muscle weakness, leading to an increased risk of falling.[8,9]

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These detrimental effects may contribute to osteoporosis and increased fracture risk in patients with a deficiency and an insufficiency of vitamin D.[10]

Clinical trials have suggested that the active form of vitamin D reduces the risk of fractures and falls.[11–13] A new analog of vitamin D, eldecalcitol, has recently been approved for the treatment of osteoporosis in Japan. Eldecalcitol has strong effects on the reduction of bone resorption and increase in bone mineral density (BMD) in addition to the effects on calcium metabolism retained by conventional vitamin D analogs.[14,15]
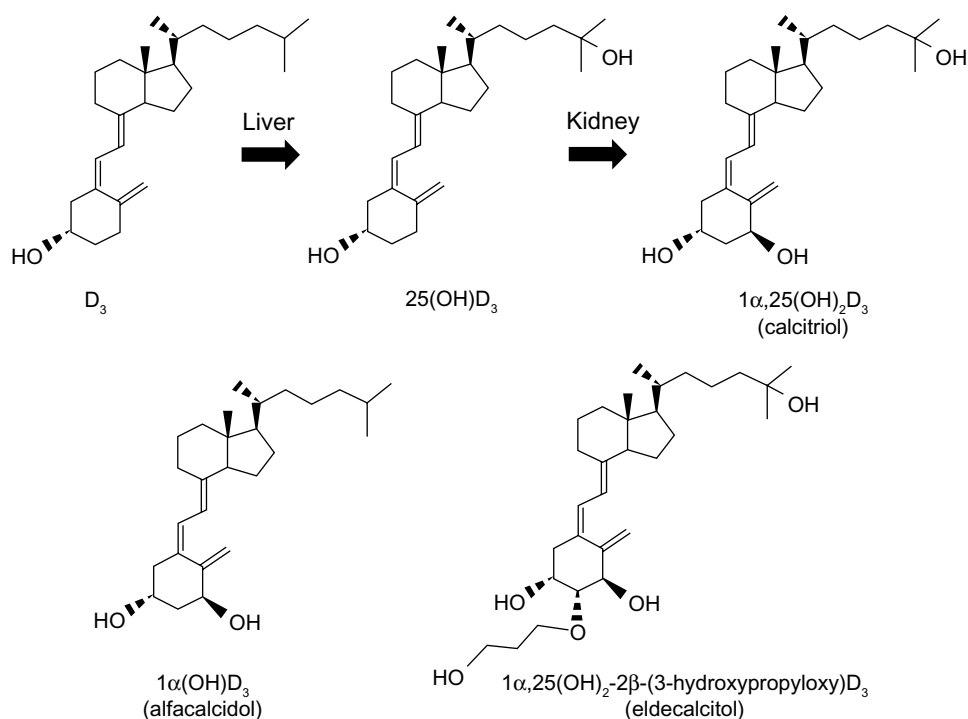
Vitamin D
Metabolism and action

Vitamin D is one of the lipid-soluble hormones produced in the skin through ultraviolet irradiation of 7-dehydrocholesterol. Vitamin D is also obtained from animal-based (vitamin D_3) or plant-based (vitamin D_2) foods.[10,16] In the human body, vitamin D is hydroxylated in the liver to 25-hydroxyvitamin D (25[OH]D) and subsequently in the kidney to its biologically active form: 1,25-dihydroxyvitamin D (1,25[OH]$_2$D) (Figure 1).[16,17] In the circulation, these vitamin D metabolites (25[OH]D and 1,25[OH]$_2$D) are bound to vitamin D-binding protein (DBP). The active metabolite 1,25(OH)$_2$D enters the cell and binds to the vitamin D receptor (VDR), which belongs to the nuclear receptor superfamily.

This ligand-bound VDR forms a heterodimer with the retinoid X receptor (RXR). The VDR/RXR complex binds to the vitamin D-responsive element on a target gene to regulate its transcription. Vitamin D regulates serum concentrations of calcium and phosphate by increasing intestinal absorption of calcium and phosphate, promoting renal reabsorption of calcium, and stimulating bone resorption.[16,18]

Vitamin D deficiency and osteoporosis

The serum level of 25(OH)D is the best indicator of vitamin D status.[19,20] Vitamin D deficiency is defined as a 25(OH)D level <20 ng/mL (50 nmol/L) and vitamin D insufficiency as a 25(OH)D level of 21–29 ng/mL (52.5–72.5 nmol/L).[4,20] Deficiency/insufficiency of vitamin D is very common in elderly people due to their low intake of vitamin D, decreased exposure to sunlight, and impaired renal function. More than one-half of postmenopausal women have a 25(OH)D level <30 ng/mL.[21,22]

Severe vitamin D deficiency can cause rickets in children and osteomalacia in adults, characterized by impaired bone mineralization.[9,10] Conversely, deficiency/insufficiency of vitamin D causes a decrease in the serum concentration of calcium due to a reduction in intestinal absorption of calcium. This hypocalcemia stimulates PTH secretion (secondary hyperparathyroidism), resulting in an increase in bone resorption and decrease of BMD. This may contribute to the

Figure 1 Chemical structures of native vitamin D_3 and active vitamin D_3 analogs.

pathogenesis of osteoporosis.[19,20] Vitamin D deficiency is also associated with muscle weakness, leading to an increased risk of falling and fractures.[8,9] A significant correlation between the serum concentration of 25(OH)D and falls in elderly people has been reported.[23–25]

Active form of vitamin D for the treatment of osteoporosis

The active form of vitamin D (1α,25-dihydroxyvitamin D_3, calcitriol) and its prodrug (1α-hydroxyvitamin D_3, alfacalcidol) have been approved for the treatment of osteoporosis in Japan (Figure 1).[26] Both calcitriol and alfacalcidol showed a modest increase in BMD,[27,28] and reduced the risk of vertebral and nonvertebral fractures.[11,12,29] The number of falls were also reduced by treatment with active vitamin D analogs.[13,28–30] Meta-analyses suggest that the vitamin D analogs (alfacalcidol and calcitriol) are more effective in preventing bone loss, fractures, and falls compared with native vitamin D.[12,31]

Eldecalcitol
Eldecalcitol: a new, active vitamin D analog

Eldecalcitol (1α, 25-dihydroxy-2β-[3-hydroxypropyloxy] vitamin D_3, ED-71) has a hydroxypropyloxy group at the 2β-position of 1,25(OH)$_2D_3$, which has been isolated from >900 vitamin D analogs, based on the activity that stimulated BMD in vivo (Figure 1).[14,15,32,33] Compared with 1,25(OH)$_2D_3$, eldecalcitol has a higher affinity for serum DBP, binds more weakly to VDR, and shows lower potency in suppression of serum PTH (Table 1).[32–35] The plasma half-life of eldecalcitol is longer than that of 1,25(OH)$_2D_3$, probably due to the higher affinity for DBP.

Preclinical studies

In ovariectomized (OVX) animal models of osteoporosis, eldecalcitol suppressed osteoclastic bone resorption and increased BMD to a greater extent than alfacalcidol. There

Table 1 Biological evaluation of eldecalcitol

Characteristics	1,25(OH)$_2D_3$	Eldecalcitol
Affinity to vitamin D receptors	100	44.6
Affinity to vitamin D-binding protein	100	422
Inhibition of parathyroid hormone secretion	100	3.54

Note: Each value of eldecalcitol represents the percentage relative to that of 1.25(OH)$_2D_3$.
Adapted from *J Steroid Biochem Mol Biol*, 103(3–5), Hatakeyama S, Nagashima S, Imai N, et al, Synthesis and biological evaluation of a 3-positon epimer of 1alpha, 25-dihydroxy-2beta-(3-hydroxypropoxy) vitamin D3 (ED-71), 222–226, Copyright (2007), with permission from Elsevier.[34]
Abbreviation: 1,25(OH)$_2D_3$, 1,25-dihydroxyvitamin D_3.

was no significant difference in calcium absorption and serum PTH suppression between eldecalcitol and alfacalcidol, so the effect of increasing BMD by eldecalcitol seems to be independent of calcium metabolism.[36] Eldecalcitol also prevented glucocorticoid-induced alterations in bone metabolism by increasing intestinal absorption of calcium, reducing osteoclastic bone resorption, and enhancing mineralization in rats.[37] Histological and histomorphological analyses revealed that eldecalcitol and alfacalcidol reduced osteoclast numbers and diminished osteoclastic activity/function without promoting osteoclast apoptosis in OVX rats.[36,38] It has been shown that administration of eldecalcitol preferentially suppressed the expression of receptor activator of nuclear factor kappa B ligand (RANKL) in osteoblast-lineage cells around the trabecular bone compared with 1,25(OH)$_2D_3$.[39] Eldecalcitol and alfacalcidol dose-dependently stimulated focal bone formation that started without prior bone resorption (bone minimodeling).[40,41] Reduction of bone resorption and stimulation of focal bone formation were more clearly observed in eldecalcitol-treated rats than in 1,25(OH)$_2D_3$-treated rats.[39,41]

Combination treatment of eldecalcitol with alendronate or raloxifene in OVX rats

In OVX rats, the combination of alendronate and eldecalcitol improved the mechanical properties of the lumbar spine and mid-shaft femur by additive suppression of bone resorption while maintaining bone formation, which was more beneficial than monotherapy with alendronate or eldecalcitol.[42] The combination of alendronate and eldecalcitol had a more beneficial antiosteoporotic effect by inhibiting osteoclastic bone resorption and maintaining osteoblastic function, compared with combination treatment with alendronate and alfacalcidol.[43] Combination treatment with eldecalcitol and raloxifene improved bone mechanical strength in OVX rats more than either type of monotherapy by increasing BMD and suppressing bone turnover.[44]

Clinical studies
Pharmacokinetics and pharmacology

A single dose of eldecalcitol (0.75 μg) was administered to 32 healthy men while fasting. The vitamin D analog was absorbed rapidly and eliminated gradually from serum, with a mean time to maximum drug concentration (T_{max}) of ~3.4 hours and a mean half-life ($t_{1/2}$) of ~53 hours.[45] The time courses of serum eldecalcitol concentrations with administration while fasting and after a meal were similar. With multiple dosing, the serum eldecalcitol concentration reached steady state by

13 days after the first dose. The pharmacokinetics of eldecalcitol were linear in the dose range 0.1–1.0 µg.[45]

To compare the effects of eldecalcitol and alfacalcidol on the metabolism of bone and calcium, a randomized open-label clinical trial was conducted in 59 post-menopausal women. Eldecalcitol could effectively inhibit bone resorption more strongly than alfacalcidol with a similar effect on bone formation and a comparable effect on urinary excretion of calcium.[46]

Phase II studies

In an early Phase II clinical trial, a randomized controlled study with eldecalcitol was conducted with 109 osteoporotic subjects. The patients were assigned randomly to 0.25, 0.5, 0.75, or 1.0 µg/day of eldecalcitol administered via the oral route for 6 months. Eldecalcitol increased lumbar BMD in a dose-dependent manner without causing hypercalcemia or hypercalciuria. Eldecalcitol also exhibited a dose-dependent suppression of a bone resorption marker (urinary deoxypyridinoline) without a significant reduction in osteocalcin.[47,48]

Many patients have serum 25(OH)D levels <20 ng/mL. Hence, the effect of eldecalcitol on bone mass might be influenced by vitamin D insufficiency and could merely reflect a nutritional supplementary effect of vitamin D insufficiency. To solve this problem, a randomized, double-blind, placebo-controlled clinical trial was conducted with 219 osteoporotic patients under vitamin D supplementation (200 or 400 IU/day). Subjects were assigned randomly to receive 0.5, 0.75, or 1.0 µg/day of eldecalcitol for 12 months. After treatment with eldecalcitol for 12 months, lumbar spine BMD increased from baseline by 2.2%, 2.6%, and 3.1% in the 0.5, 0.75, and 1.0 µg eldecalcitol groups, respectively; whereas, lumbar spine BMD decreased by 0.7% in the placebo group. Total hip BMD also increased with 0.75 and 1.0 µg eldecalcitol from baseline by 0.6% and 0.9%, respectively. Conversely, in the placebo and 0.5 µg eldecalcitol group, total hip BMD decreased slightly from baseline (−0.9% and −0.8%). Markers of bone formation and resorption were suppressed by ≈20% after 12 months of treatment with 0.75 and 1.0 µg eldecalcitol. Transient increase in serum calcium level >10.4 mg/dL (>2.6 mmol/L) occurred in 7%, 5%, and 23% of subjects in the 0.5, 0.75, and 1.0 µg eldecalcitol groups, respectively; but none of them developed sustained hypercalcemia.[49] Post hoc analyses of the trial revealed that eldecalcitol could increase lumbar and hip BMD in osteoporotic patients, regardless of their vitamin D status.[50] These results suggest that eldecalcitol can exert its effect on bone independently of the nutritional supplementation with native vitamin D.

Phase III studies

Based on the results of Phase II clinical studies, a 3-year, randomized, double-blind, active comparator, superiority trial was carried out to compare the effect of eldecalcitol (0.75 µg/day) with that of alfacalcidol (1 µg/day) in preventing fractures in patients with osteoporosis.[51] A total of 1,054 patients aged 46–92 years (mean, 72.1 years) were assigned randomly to receive eldecalcitol (n = 528) or alfacalcidol (n = 526). Patients with low serum levels of 25(OH)D (<20 ng/mL) were supplemented with 400 IU/day of vitamin D_3. Compared with the alfacalcidol group, the incidence of vertebral fractures was lower in the eldecalcitol group after 36 months of treatment (13.4% versus 17.5%) with a relative risk reduction of 26% ($P = 0.092$; hazard ratio [HR] 0.74; 90% confidence interval [CI]: 0.56–0.97) (Figure 2). The incidence of new vertebral fractures was not different between the two groups during the first year, but was significantly lower in the eldecalcitol group during the third year (3.9% versus 7.0%, odds ratio [OR] 0.51, $P = 0.037$; 95% CI 0.27–0.97). With regard to the total number of nonvertebral fractures at 36 months, no significant difference was observed between the eldecalcitol and alfacalcidol groups (8.0% versus 9.5%, HR 0.85, 95% CI 0.55–1.31). However, eldecalcitol reduced the incidence of three major nonvertebral fractures (humerus, wrist, hip) compared with alfacalcidol (2.5% versus 4.9%, HR 0.51, 95% CI 0.25–1.03), which was due, in particular, to a marked decrease in the incidence of wrist fractures (1.1%
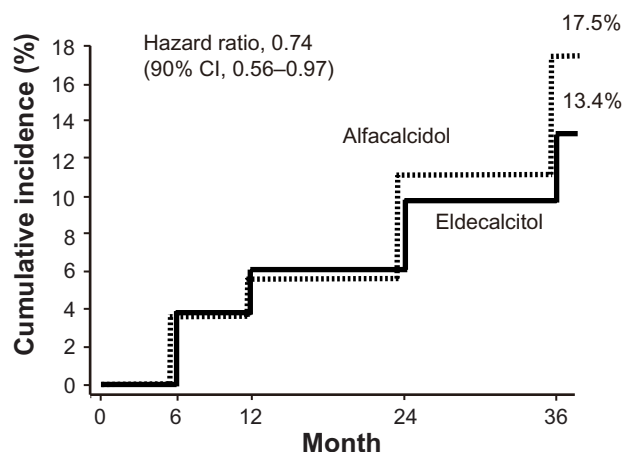
Figure 2 Incidence of new vertebral fractures in the alfacalcidol (1.0 µg/day) group and the eldecalcitol (0.75 µg/day) group during the 3-year study period. Kaplan–Meier estimates of the incidence of new vertebral fractures.
Adapted from Matsumoto T, Ito M, Hayashi Y, et al. A new active vitamin D3 analog, eldecalcitol, prevents the risk of osteoporotic fractures – a randomized, active comparator, double-blind study. *Bone.* 2011;49(4):605–612, with permission from Elsevier.[51]
Abbreviation: CI, confidence interval.

versus 3.6%, HR 0.29, 95% CI 0.11–0.77, $P = 0.009$) (Figure 3). Eldecalcitol increased lumbar and hip BMD more strongly than alfacalcidol (Figures 4A and B). Levels of bone turnover markers (bone-specific alkaline phosphatase [BSAP] and urinary crosslinked N-telopeptide of type-I bone collagen [NTX]) were significantly lower with eldecalcitol than with alfacalcidol (Figures 4C and D). The decrease from baseline in bone turnover markers after the eldecalcitol treatment exceeded the minimum significant change, authorized by the Japan Osteoporosis Society.[52] These results suggest that eldecalcitol is more efficacious than alfacalcidol in preventing vertebral and wrist fractures in osteoporotic patients.[51]

Among the adverse events, the prevalence of an increase in serum and urinary levels of calcium was higher in the eldecalcitol group compared with the alfacalcidol group (Table 2). Increased serum calcium was observed in 21.0% of eldecalcitol recipients and 13.5% of alfacalcidol recipients, while hypercalcemia developed in two patients (0.4%) in the eldecalcitol group but none in the alfacalcidol group. There was no significant difference in the prevalence of urolithiasis and in the estimated glomerular filtration rate between the two groups.[51]

Post hoc analyses of the Phase III study

Post hoc analyses of the Phase III study revealed that the incidence of vertebral fracture at the lower spine was lower in the eldecalcitol group than in the alfacalcidol group ($P = 0.029$). The incidence of severe vertebral fractures (grade III) was lower in the eldecalcitol group than in the alfacalcidol group (3.8% versus 6.7%; HR, 0.53; 95% CI, 0.29–0.96; $P = 0.036$). Eldecalcitol and alfacalcidol improved health-related quality of life (HRQoL) scores, but overall improvement from the baseline of HRQoL scores was observed clearly in the eldecalcitol group.[53]

Eldecalcitol reduced the incidence of osteoporotic fractures, as defined by the World Health Organization, more than alfacalcidol (18.6% versus 25.2%; HR, 0.70; 90% CI, 0.54–0.93; $P = 0.013$) and decreased the risk of major osteoporotic fractures included in the Fracture Risk Assessment Tool (FRAX)[54] (11.1% versus 16.3%; HR, 0.66; 95% CI, 0.46–0.94; $P = 0.020$). A significant decrease in the incidence of nonvertebral fractures was also observed in the eldecalcitol group.[55]

To ascertain if eldecalcitol can cause severely suppressed bone turnover, post hoc analyses of the Phase III trial about the changes in bone turnover markers after eldecalcitol
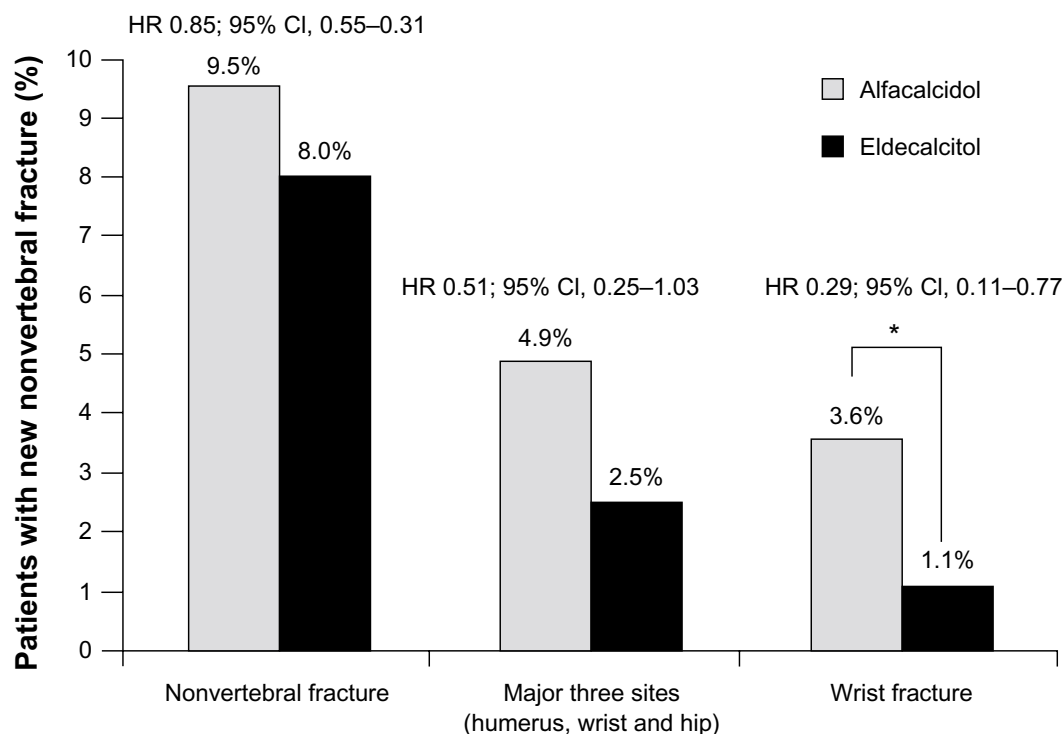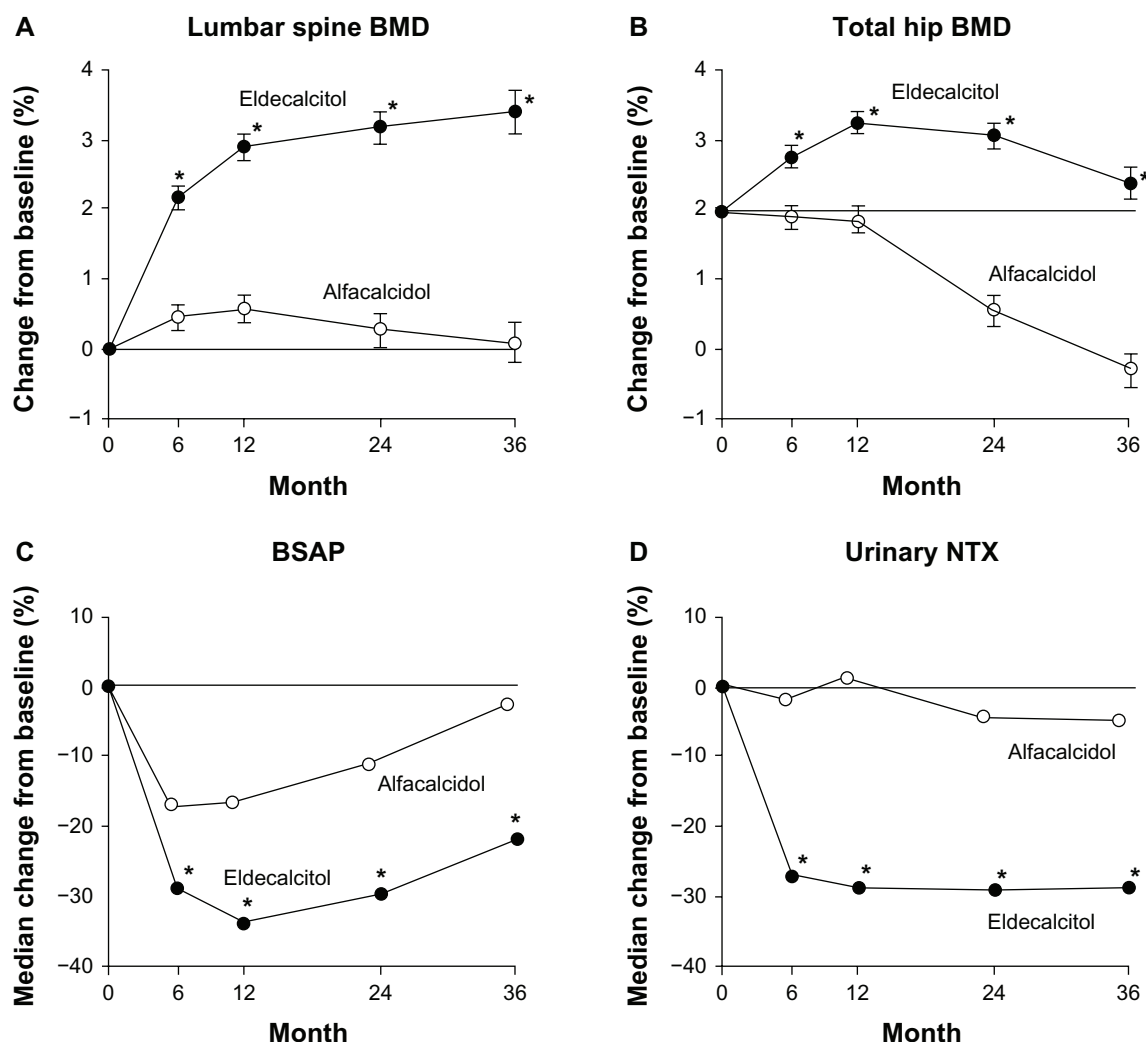

Figure 3 Incidence of all nonvertebral fractures, nonvertebral fractures at three major sites (humerus, wrist, hip), and wrist fracture in the alfacalcidol (1.0 µg/day) group and the eldecalcitol (0.75 µg/day) group during the 3-year study period.
Notes: *$P = 0.009$. Data from.[51]
Abbreviations: HR, hazard ratio; CI, confidence interval.

Figure 4 Effects of eldecalcitol and alfacalcidol on BMD (**A** and **B**) and bone turnover markers (**C** and **D**) during the 3-year study period.
Notes: Mean percent change from baseline in lumbar spine (**A**) and total hip (**B**) BMD in the eldecalcitol group (closed circle) and the alfacalcidol group (open circle) during the study period. Median percent change from baseline in bone turnover markers including serum BSAP (**C**) and urinary NTX (**D**) in the eldecalcitol group (closed circle) and the alfacalcidol group (open circle) during the study period are shown. Data are means ± SE for lumbar spine and total hip BMD, and medians for bone turnover markers. *$P < 0.001$ in comparison with alfacalcidol.
Adapted from Matsumoto T, Ito M, Hayashi Y, et al. A new active vitamin D3 analog, eldecalcitol, prevents the risk of osteoporotic fractures – a randomized, active comparator, double-blind study. *Bone.* 2011;49(4):605–612, with permission from the Elsevier.[51]
Abbreviations: BMD, bone mineral density; BSAP, bone-specific alkaline phosphatase; NTX, urinary N-terminal propeptide of type I collagen; SE, standard error.

treatment in osteoporotic patients were undertaken. Eldecalcitol reduced markers of bone turnover rapidly and kept them within the normal range. In patients whose baseline values for bone turnover markers were low, eldecalcitol treatment did not reduce the bone turnover markers further during a 3-year treatment period.[56]

The effects of eldecalcitol on bone geometry and the biomechanical properties of the proximal femur were investigated by computed tomography in a subgroup of the Phase III study (n = 193). Longitudinal analyses of hip geometry revealed the advantages of eldecalcitol over alfacalcidol in: increased cortical cross-sectional area; volumetric BMD of the neck and shaft of the femur; bone mass; and

maintenance of cortical thickness (probably through mitigating endocortical bone resorption). By improving the biomechanical properties of the proximal femur, eldecalcitol could reduce the risk of hip fracture.[57]

Place of eldecalcitol in the treatment of osteoporosis

The vitamin D analogs alfacalcidol and calcitriol have been used for the treatment of osteoporosis in Japan. However, these drugs are not used as first-line therapy for osteoporosis, because they have weaker inhibitory effects on fractures than bisphosphonates, selective estrogen receptor modulators, or teriparatide. The new active form of vitamin D, eldecalcitol,

Table 2 Incidence of adverse events

Event	Eldecalcitol (N = 528)	Alfacalcidol (N = 526)	Risk ratio	95% confidence interval
General				
Any adverse events	520 (98.5%)	518 (98.5%)	1.00	0.99–1.02
Nasopharyngitis	332 (62.9%)	312 (59.3%)	1.06	0.96–1.17
Contusion	119 (22.5%)	118 (22.4%)	1.00	0.80–1.26
Urine calcium increased	135 (25.6%)	82 (15.6%)	1.64	1.28–2.10
Blood calcium increased	111 (21.0%)	71 (13.5%)	1.56	1.19–2.04
Back pain	72 (13.6%)	81 (15.4%)	0.89	0.66–1.19
Osteoarthritis	82 (15.5%)	70 (13.3%)	1.17	0.87–1.57
Arthralgia	54 (10.2%)	52 (9.9%)	1.03	0.72–1.48
Eczema	54 (10.2%)	50 (9.5%)	1.08	0.75–1.55
Constipation	39 (7.4%)	58 (11.0%)	0.67	0.45–0.99
Headache	51 (9.7%)	39 (7.4%)	1.30	0.87–1.94
Diarrhea	50 (9.5%)	38 (7.2%)	1.31	0.88–1.96
Gastroenteritis	46 (8.7%)	41 (7.8%)	1.12	0.75–1.67
Periarthritis	45 (8.5%)	41 (7.8%)	1.09	0.73–1.64
Spinal fracture	38 (7.2%)	46 (8.7%)	0.82	0.54–1.24
Cystitis	36 (6.8%)	44 (8.4%)	0.82	0.53–1.24
Hypertension	41 (7.8%)	36 (6.8%)	1.13	0.74–1.75
Gastritis	34 (6.4%)	40 (7.6%)	0.85	0.54–1.32
Pain in extremity	31 (5.9%)	40 (7.6%)	0.77	0.49–1.21
Stomatitis	37 (7.0%)	32 (6.1%)	1.15	0.73–1.82
Dermatitis contact	38 (7.2%)	28 (5.3%)	1.35	0.84–2.17
Insomnia	34 (6.4%)	32 (6.1%)	1.06	0.66–1.69
Dizziness	29 (5.5%)	32 (6.1%)	0.90	0.55–1.47
Cataract	32 (6.1%)	27 (5.1%)	1.18	0.72–1.94
Joint sprain	29 (5.5%)	28 (5.3%)	1.03	0.62–1.71
Spinal osteoarthritis	23 (4.4%)	34 (6.5%)	0.67	0.40–1.13
Stomach discomfort	27 (5.1%)	25 (4.8%)	1.08	0.63–1.83
Exanthem	15 (2.8%)	33 (6.3%)	0.45	0.25–0.82
Serious adverse events	110 (20.8%)	134 (25.5%)	0.82	0.66–1.02
Death	4 (0.8%)	6 (1.1%)	0.66	0.19–2.34
Cancer	11 (2.1%)	16 (3.0%)	0.68	0.32–1.46
Discontinued due to adverse events	31 (5.9%)	40 (7.6%)	0.77	0.49–1.21
Calcium-related adverse events				
Urolithiasis	7 (1.3%)	5 (1.0%)	1.39	0.45–4.37

Note: Adapted from Matsumoto T, Ito M, Hayashi Y, et al. A new active vitamin D3 analog, eldecalcitol, prevents the risk of osteoporotic fractures – a randomized, active comparator, double-blind study. *Bone*. 2011;49(4):605–612, with permission from Elsevier.[51]

has stronger effects on the inhibition of bone resorption, increases BMD, and prevents osteoporotic fractures compared with alfacalcidol. It has been reported that native and active vitamin D reduced the risk of falling among older individuals.[13] There are no data regarding the efficacy of eldecalcitol for preventing falls, but marked inhibition of wrist fractures by eldecalcitol may be explained (at least in part) by the preventive effects of the drug on falling. Moreover, it has recently been noted that low serum levels of vitamin D are associated with several adverse outcomes in the musculoskeletal, innate

immune, and cardiovascular systems; and they are also associated with increased all-cause mortality.[19,20] Eldecalcitol has effects on the metabolism of bone and calcium and may prevent falling, so multiple improvements in patients with osteoporosis can be expected with only one drug, which may lead to a reduction in the health care burden. Eldecalcitol would be preferable, especially for elderly people with osteoporosis, because of the high prevalence of vitamin D deficiency. It has recently been indicated that children, young adults, and middle-age adults are at an equally high risk for vitamin D deficiency/insufficiency,[4,20] so osteoporosis in young people may also be a target for treatment with eldecalcitol.

In preclinical studies using OVX rats, favorable results have been obtained upon combination treatment of eldecalcitol with alendronate or raloxifene. Clinical studies have indicated the advantages of combination therapy with alfacalcidol and alendronate for the prevention of osteoporosis-related fractures.[58,59] In the post hoc analyses of the Phase III trial, eldecalcitol normalized and did not overly suppress bone turnover – even in patients with low pretreatment levels of bone turnover markers.[56] These results may raise expectation of combined therapy with eldecalcitol and antiresorptive agents; however, clinical data for the combined therapy – including eldecalcitol – have not been available to date. Future clinical studies regarding the combination treatment of eldecalcitol with other drugs for osteoporosis are required.

The precise pharmacological action of the active form of vitamin D on bone metabolism is not fully understood. It has been shown that c-Fos and RANKL may be the targets of the action of vitamin D.[39,60] Although eldecalcitol and $1,25(OH)_2D_3$ are known to enhance RANKL expression in vitro, eldecalcitol suppresses the expression of RANKL in osteoblast-lineage cells and reduces the bone resorption in vivo.[39,40] This discrepancy between in vitro and in vivo studies has not been fully explained. Recent histological analyses in OVX rats revealed that the preosteoblastic layer, with which osteoclastic precursors interact for mutual differentiation, was poorly developed in eldecalcitol-treated rats.[40] Eldecalcitol also promoted focal bone formation, known as bone minimodeling, which is independent of bone resorption. The increased macrophage number and the decreased osteoclast number in the bone marrow of eldecalcitol-treated rats were also observed.[40] It has also been reported that RANKL was expressed preferentially by immature osteoblasts, and the expression level decreased during their maturation.[61] Based on these results, eldecalcitol may force osteoblast maturation and prevent cell-to-cell interaction between preosteoblasts and osteoclastic precursors, leading to lower osteoclast number and decreased bone resorption.

A recent study revealed that the active form of vitamin D, including eldecalcitol, significantly suppressed the expression of bone tropic S1PR2 in circulating osteoclast precursor monocytes. As a result, mobilization of the osteoclast precursor monocytes from the bone to the blood was enhanced, causing a suppression of bone resorption.[62]

Conclusion

Eldecalcitol possesses a strong inhibitory effect on bone resorption and causes a significant increase in BMD. Phase III clinical trials revealed that the incidence of vertebral and wrist fractures was significantly reduced in the eldecalcitol group compared with the alfacalcidol group. To date, eldecalcitol is not available outside of Japan. Therefore, all clinical trials have been conducted in Japan. This unique vitamin D analog is thought to be useful, especially for patients with osteoporosis and vitamin D deficiency. Approval of the drug for osteoporosis treatment in other countries is expected. Increases in blood and urinary levels of calcium were the most frequent adverse events in the treatment with eldecalcitol, though hypercalcemia was observed in only a few patients. Blood and urinary calcium should be monitored during eldecalcitol treatment. Large-scale clinical trials that compare the effects of eldecalcitol with other drugs for osteoporosis, as well as evaluation of combination therapy, should be carried out.

Disclosure

The authors report no conflicts of interest in this work.

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