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Active vitamin D possesses beneficial effects on the interaction between muscle and bone

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ABSTRACT

Vitamin D deficiency and advanced glycation end products (AGEs) are suggested to be involved in the pathogenesis of osteoporosis and sarcopenia. However, the effects of vitamin D and AGEs on myogenesis and the interaction between muscle and bone remains still unclear. We previously showed that osteoglycin (OGN) is secreted from myoblasts and stimulates osteoblastic differentiation, suggesting that it plays important roles in the interaction between muscle and bone. The aim of this study is thus to examine the effects of vitamin D and AGEs on myoblastic differentiation of C2C12 cells and osteoblastic differentiation of osteoblastic MC3T3-E1 cells through OGN expression. 1α,25-dihydroxyvitamin D_3 (1,25D) and eldecalcitol, an active vitamin D analog, induced the expression of MyoD, myogenin and OGN, and these effects were abolished by vitamin D receptor (VDR) suppression by siRNA in C2C12 cells. Moreover, conditioned medium from 1,25D-pretreated C2C12 cells stimulated the expression of type 1 collagen and alkaline phosphatase in MC3T3-E1 cells, compared to control medium from 1,25D-untreated C2C12 cells. In contrast, conditioned medium from VDR-suppressed and 1,25D-pretreated C2C12 cells showed no effects. AGE2 and AGE3 suppressed the expression of MyoD, myogenin and OGN in C2C12 cells. Moreover, 1,25D blunted the AGEs' effects. In conclusion, these findings showed for the first time that active vitamin D plays important roles in myogenesis and muscle-induced osteoblastogenesis through OGN expression. Active vitamin D treatment may rescue the AGEs-induced sarcopenia as well as – suppressed osteoblastic differentiation via OGN expression in myoblasts.

1. Introduction

The number of patients with aging-related diseases, such as sarcopenia and osteoporosis, has been increasing rapidly worldwide in recent years. Indeed, it is reported that more than 30% in elderly people over the age of 80 years suffered from sarcopenia and/or osteoporosis [1]. A number of studies on the causes and treatments of sarcopenia have been performed. Several clinical studies have shown that vitamin D deficiency is associated with an increased risk of falls, and that vitamin D supplementation reduces the risk in vitamin D-deficient patients [2–5]. 1α,25-dihydroxyvitamin D_3 (1,25D) enhanced myoblastic differentiation through modulating growth factors and fast-myosin heavy chain expression in mouse myoblastic C2C12 cells [6,7]. On the other hand, there are also numerous studies on the effects of vitamin D on bone cells such as osteoblasts, osteoclasts, and osteocytes. Regarding the effects of vitamin D on bone formation, several studies reported that 1,25D exerted direct effects on osteoblasts and induced their differentiation and mineralization via the vitamin D receptor (VDR) [8,9]. These findings indicate that vitamin D may be essentials to muscle and bone strength.

Cumulative evidence has shown that there is a positive correlation between lean body mass and bone mineral density (BMD), suggesting that muscle and bone are related to each other [10]. Although the mechanism of the interaction between muscle and bone is still unclear, we recently showed that osteoglycin (OGN), which is the seventh member of the small leucine-rich proteoglycans and was initially isolated from bovine bone as an inducer of matrix mineralization [11], was a crucial humoral factor linking muscle to bone [12]. OGN overexpression in myoblastic cells

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induced osteoblast phenotype and mineralization in osteoblastic cells, suggesting that OGN is an important molecule for the interaction between muscle and bone tissues. However, regulatory factors of OGN are not reported so far.

It has been shown that the risk of osteoporotic fracture is increased in diabetic patients [13]. Advanced glycation end products (AGEs) are produced by non-enzymatic reactions of carbohydrates with proteins especially in diabetic status and elderly people [14,15]. AGEs adversely affect bone: we showed that the combination of high glucose and AGE2 or AGE3 inhibited the mineralization of osteoblastic MC3T3-E1 cells, and that AGE2 or AGE3 inhibited the osteoblastic differentiation and mineralization of mouse stromal ST2 cells [16–19]. On the other hand, several studies have shown that sarcopenia is associated with diabetes mellitus [20–23]. Previous studies showed that serum AGE levels were significantly correlated with weak grip strength and walking disability in elderly women [24,25]. These findings suggest that AGEs adversely affect both bone and muscle tissues, causing osteoporosis and sarcopenia, respectively, in type 2 diabetes. However, there are no studies on the direct effects of AGEs on myoblasts and osteoinductive factors derived from muscle.

In this study, we thus examined the roles of active vitamin D in the interaction between muscle and bone. In addition to 1,25-dihydroxyvitamin D_3 (1,25D), 25-hydroxyvitamin D_3 (25D), and 24,25-dihydroxyvitamin D_3 (24,25D), we used eldecalcitol (ELD), which is a novel analog of active vitamin D and recently became available for clinical use, because there are no studies on its direct effects on myoblasts. Moreover, we investigated whether or not active vitamin D can rescue the AGEs' adverse effects on myoblastic differentiation.

2. Materials and methods

2.1. Materials

Recombinant 1,25D, 25-hydroxyvitamin D_3 (25D), and 24,25-dihydroxyvitamin D_3 (24,25D), and ELD are kindly provided by Chugai Pharma. Anti-β-actin antibody was obtained from Sigma–Aldrich Corp (St. Louis, MO). Anti-Alkaline Phosphatase (ALP), anti-OGN, anti-myogenin, anti-MyoD, anti-VDR antibodies, VDR siRNA, and control siRNA were from Santa Cruz Biotechnology (Santa Cruz, CA, USA). Anti-type 1 collagen (Col1) antibody was from Calbiochem and Ingenex Corp. (San Diego, CA, USA). All other chemicals used were of analytical grade.

2.2. Cell culture

Mouse myoblastic C2C12 cells (ATCC) were cultured in Dulbecco's modified Eagle's medium (DMEM) (Invitrogen) with 10% fetal bovine serum (FBS) and 1% penicillin–streptomycin (Invitrogen). The cells were cultured in DMEM with 2% horse serum for 6 days to differentiate into myotube. Mouse osteoblastic MC3T3-E1 cells were provided by Dr. H. Komada (Ohu Dental Collage, Koriyama, Japan). The cells were cultured in α-MEM with 10% FBS and 1% penicillin–streptomycin. The medium was changed twice a week.

2.3. Conditioned medium collection

After reached cell confluent, C2C12 cells were incubated with or without 1,25D for 2 days. After that, the cells were washed and incubated in DMEM without FBS and 1,25D for 24 h. Then, the medium was collected and stored at −80 °C. The medium from vitamin D-untreated cells was used as controls. The conditioned medium was added at 20% of final concentration in α-MEM when effects of the conditioned medium on MC3T3-E1 cells were examined.

2.4. Preparation of AGEs

AGE2, AGE3, and nonglycated BSA were prepared as previously described [16–18]. AGE2 and AGE3 were prepared by incubating 50 mg/mL BSA (Sigma, St. Louis, MO) with 0.1 M DL-glyceraldehyde (Nacalai Tesque, Kyoto, Japan) and 0.1 M glycolaldehyde (Sigma), respectively, under sterile conditions in 0.2 M phosphate buffer (pH 7.4) containing 5 mM diethylene-triamine-pentaacetic acid (DTPA) at 37 °C for 7 days. Nonglycated BSA was incubated under the same conditions except for the absence of DL-glyceraldehyde or glycolaldehyde as a negative control. Then low molecular weight reactants and aldehydes were removed using a PD-10 column chromatography and dialysis against phosphate-buffered saline (PBS).

2.5. Protein extraction and Western blot analysis

Cells were lysed with radioimmunoprecipitation buffer containing 0.5 mM phenylmethylsulfonylfluoride, complete protease inhibitor mixture (Roche Applied Science, Tokyo, Japan), 1% Triton X-100 and 1 mM sodium orthovanadate. Proteins were transferred in 25 mM Tris, 192 mM glycine and 20% methanol to polyvinylidene difluoride. Blots were blocked with 20 mM Tris–HCl (pH 7.5), 137 mM NaCl, 0.1% Tween 20 and 3% dried milk powder. The membranes were immunoblotted with each primary antibody. The antigen–antibody complexes were visualized using the appropriate secondary antibodies (Sigma–Aldrich Corp.) and an enhanced chemiluminescence detection system, LAS-4000 IR multi color (FUJIFILM). The results depicted in each figure are representative of at least three independent cell preparations. Each experiment was repeated three times.

2.6. RNA extraction and real-time PCR

Total RNA was prepared from cells using Trizol reagent (Invitrogen, San Diego, CA). cDNA was synthesized using a SuperScript-III cDNA synthesis kit (Invitrogen). Specific mRNA was quantified by using an ABI PRISM 7000 sequence detection system (Applied Biosystems Inc.) with SYBR Premix Ex TaqTM II (Perfect Real Time) kits (TaKaRa) according to the manufacturer's standard protocol. The mRNA value for each gene was normalized relative to the mouse GAPDH mRNA levels in RNA samples. Primer sequences (forward and reverse) were as follows:

GAPDH, 5′-GTGTACATGGTTCCAGTATGAGTCC-3′ and 5′-AGT GAGTTGTCATATTTCTCGTGGT-3′; OGN, 5′-TGCTTTGTGGTCACATG GAT-3′ and 5′-GAAGCTGCACACAGCACAAT-3′; Myogenin, 5′-GCTG CCTAAAGTGGAGATCCT-3′ and 5′-GCGCTGTGGGAGTTGCAT-3′; MyoD, 5′-GACGGCTCTCTCTGCTCCTT-3′ and 5′-AGTAGAGAAGTGTG CGTGCT-3′.

2.7. Transfection of small interfering RNA (siRNA)

Mouse VDR siRNA or control siRNA were transfected into C2C12 cells with LipofectAMINE (Invitrogen). Six hours later, the cells were fed with fresh medium containing 10% FBS, and the transfected cells were harvested for 48 h and were used for the experiments.

2.8. Statistics

All experiments were repeated at least three times. Data are expressed as mean ± S.E. Statistical analysis was performed using analysis of variance. A P value <0.05 was taken to indicate a significant difference.

3. Results

3.1. Effects of vitamin Ds on the expression of OGN and myoblastic differentiation in myoblastic cells

We first examined the effects of 1,25D on the expression of OGN and myoblastic differentiation in myoblastic C2C12 cells. As shown in Fig. 1A, 10^{-10} M 1,25D markedly increased the expressions of OGN and myogenin proteins after 48-h incubation in these cells. Moreover, 1,25D increased the expressions of OGN, myogenin, and MyoD proteins (10^{-11}M–10^{-8}M) (Fig. 1B). Next, we examined the effects of vitamin D on the expressions of OGN, myogenin, and MyoD. As shown in Fig. 1C, 10–10 M ELD as well as 1,25D increased the expressions of OGN, myogenin, and MyoD proteins, although 10^{-10}M 25D or 24,25D did not affect them. Moreover, 10^{-10}M 1,25D and ELD significantly increased the mRNA levels of OGN, myogenin, and MyoD although 10^{-10}M 25D or 24,25D did not affect them (Fig. 1D–F).

3.2. Effects of a reduction in endogenous VDR by siRNA on 1,25D- and eldecalcitol-induced OGN expression in myoblastic cells

We examined the effects of a reduction in endogenous VDR by siRNA on 1,25D- and ELD-induced OGN expression in C2C12 cells. We confirmed that the level of VDR protein was suppressed by VDR siRNA transfection by Western blot analysis (Fig. 2A). As shown in Fig. 2B, a reduction in endogenous VDR by siRNA suppressed 1,25D- and ELD-induced expression of OGN protein. Moreover, a reduction in endogenous VDR by siRNA significantly suppressed 1,25D- and ELD-induced the expression of OGN mRNA (Fig. 2C).

3.3. Effects of conditioned medium from 1,25D-pretreated and/or VDR siRNA-transfected myoblastic cells on osteoblast phenotype

We examined the effects of conditioned medium from 1,25D-pretreated and/or VDR siRNA-transfected C2C12 cells on osteoblast phenotype of MC3T3-E1 cells. Before using the conditioned medium, we confirmed that the level of OGN protein was increased in conditioned medium from 1,25D-pretreated C2C12 cells compared with control medium (Fig. 3A). The conditioned medium from 1,25D-pretreated C2C12 cells increased the expressions of Col1 and ALP proteins compared with controls in MC3T3-E1 cells (Fig. 3B). Moreover, the expressions of Col1 and ALP proteins were partially suppressed by conditioned medium from 1,25D-pretreated C2C12 cells knocked down by VDR siRNA, compared with the conditioned medium from 1,25D-pretreated C2C12 cells without VDR silencing (Fig. 3C).

3.4. Effects of AGEs as well as co-incubation with 1,25D and AGEs on myoblastic differentiation and the expression of OGN in myoblastic cells

We investigated the effects of AGE2 or AGE3 on myoblastic differentiation in C2C12 cells. As shown in Fig. 4A, 200 μg/mL

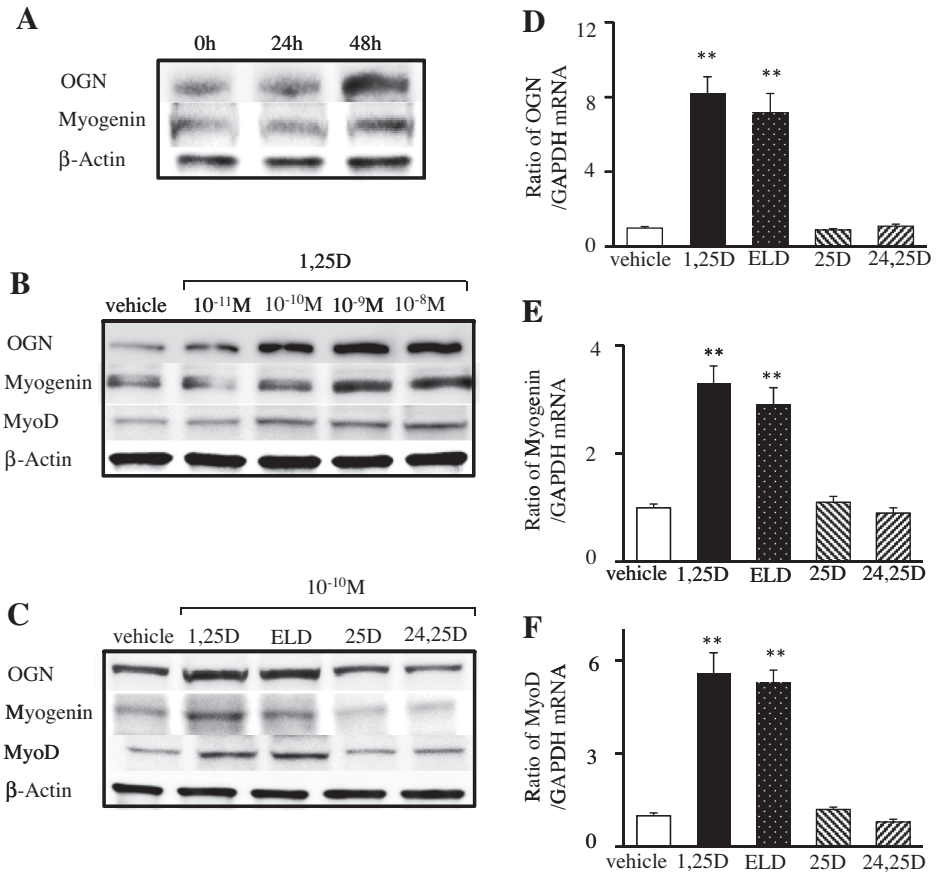

Fig. 1. 1,25D and ELD induced the expression of OGN and myoblastic differentiation in myoblastic cells. (A) Total proteins were extracted from 10^{-10}M 1,25D-pretreated C2C12 cells after 0-, 24-, or 48-h incubation. (B) Total proteins were extracted from 10^{-11} to 10^{-8}M 1,25D-pretreated C2C12 cells after 48-h incubation. (C) Total proteins were extracted from 10^{-10}M 1,25D- or ELD-pretreated C2C12 cells after 48-h incubation. (D-F) Total RNAs were extracted from 10^{-10}M 1,25D-, ELD-, 25D-, or 24,25D-pretreated C2C12 cells after 24-h incubation. Western blot analysis was performed with anti-OGN, myogenin, MyoD, or β-actin antibodies. Real-time PCR was performed and data were expressed as the GAPDH mRNA ratio. $^{**}P < 0.01$ relative to control.

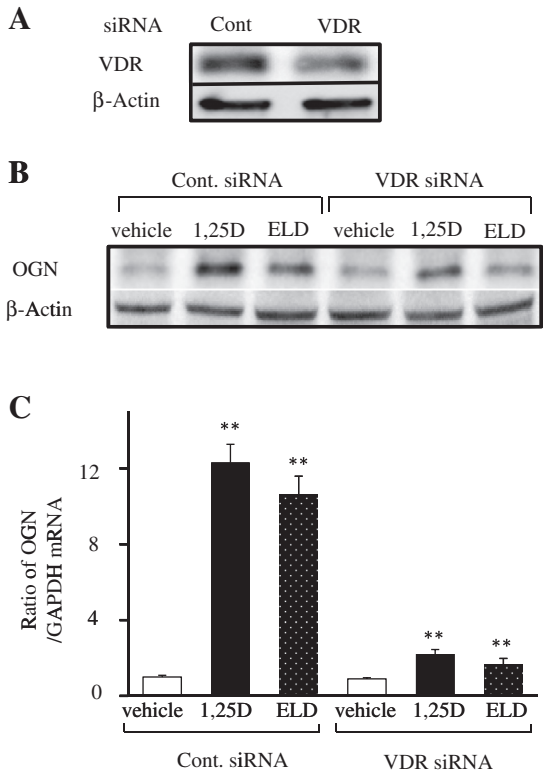

Fig. 2. A reduction in endogenous VDR by siRNA suppressed activated vitamin D-induced OGN expression in myoblastic cells. (A) Total proteins were extracted from control siRNA- or VDR siRNA-transfected C2C12. (B) Total proteins were extracted from 10^{-10}M 1,25D- or EDL-pretreated C2C12 cells for 48 h with control siRNA- or VDR siRNA-transfection. (C) Total RNAs were extracted from 10^{-10}M 1,25D- or ELD-pretreated C2C12 cells for 24 h with control siRNA- or VDR siRNA-transfection. Western blot analysis was performed with anti-VDR, anti-OGN or β-actin antibodies. Real-time PCR was performed and data were expressed as the GAPDH mRNA ratio. $^{**}P < 0.01$ relative to vehicle with control siRNA-transfection or with VDR siRNA-transfection.

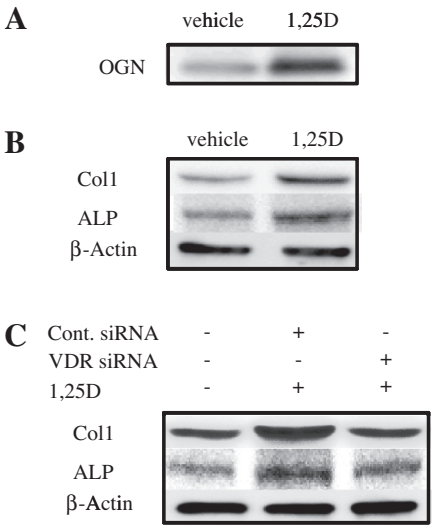

Fig. 3. Conditioned medium from 1,25D-pretreated myoblastic cells induced osteoblast phenotype in MC3T3-E1 cells. After reached cell confluent, C2C12 cells were incubated with or without 1,25D for 2 days. After that, the cells were washed and incubated in DMEM without FBS and 1,25D for 24 h. Then, the medium was collected. (A) Western blot analysis was performed with anti-OGN antibody using 10 μL medium and loading buffer. (B) MC3T3-E1 cells were cultured with 20% of each conditioned medium for 48 h. Total protein from these cells was extracted, and Western blot analysis was performed with anti-Col1, ALP, or β-actin antibodies. (C) Conditioned medium was obtained from the cultures of control siRNA- or VDR siRNA-transfected C2C12 cells with or without 1,25D.

AGE2 or AGE3 markedly suppressed the expressions of MyoD and myogenin (Fig. 4A) as well as OGN protein (Fig. 4B) in C2C12 cells. Moreover, AGE2 or AGE3 significantly inhibited the mRNA expression of MyoD, myogenin, and OGN (Fig. 4C–E). Finally, we examined the effects of 1,25D on AGEs-suppressed myoblastic differentiation and the expression of OGN in C2C12 cells. As shown in Fig. 4F, 10–10 M 1,25D recovered AGE2- or AGE3-suppressed expressions of MyoD and myogenin proteins. Moreover, 1,25D recovered AGE2- or AGE3-suppressed the levels of OGN protein (Fig. 4G).

4. Discussion

The interaction between muscle and bone has recently attracted widespread attention. We previously found that OGN is a humoral molecule derived from myoblast and might induce the osteogenic differentiation [12]. Since vitamin D is well-known to be an important factor for myoblastic differentiation and muscle strength [7,26], we hypothesized that vitamin D might affect OGN expression in myoblasts. Along with the markers of myogenesis, the expression of OGN mRNA and protein was increased by 1,25D and ELD in C2C12 cells. And, 1,25D- and ELD-induced OGN expression was partially but significantly canceled by VDR silencing by siRNA. In addition, the conditioned medium from 1,25D-pretreated C2C12 cells increased Col1 and ALP expression in MC3T3-E1 cells. This is the first evidence that active vitamin D is involved in the interaction between muscle and bone probably via OGN expression.

Although receptor for AGEs (RAGE) is expressed in muscle [27], the direct effects of AGEs on myoblastic differentiation were not reported. We previously demonstrated that AGE2 and AGE3, which are related to diabetic complications [14,15], inhibited the differentiation of stromal cells into osteoblasts and the mineralization of osteoblastic cells through RAGE expression [16,17], suggesting that AGEs directly affect osteoblast function and bone formation. In the present study, we showed that AGE2 and AGE3 suppressed the myoblastic differentiation and the expression of OGN in C2C12 cells, suggesting that AGEs have direct negative effects on myogenesis and indirect negative effects on osteoblastic differentiation probably through suppressing OGN expression in myoblasts.

Our previous and present studies suggest that AGEs are important factors in the pathology of not only sarcopenia but also osteoporosis. Regarding the prevention and treatment of these diseases, the agents that abolish the effects of AGEs should be clinically important. Thus, we tested the effects of co-incubation with 1,25D and AGEs on myoblastic differentiation and OGN expression. While AGEs decreased the expressions of MyoD, myogenin and OGN, 1,25D markedly increased them under the presence of AGEs. These findings indicate that 1,25D treatment might be useful to prevent sarcopenia and osteoporosis associated with diabetes mellitus and elderly people.

We previously reported that AGEs inhibited the osteoblastic differentiation of stromal ST2 cells by suppressing endoplasmic reticulum (ER) stress sensors such as inositol-requiring transmembrane kinase and endonuclease 1α, activating transcription factor 6, and old astrocyte specifically induced substance, which leads to the accumulation of abnormal proteins [18]. Previous studies also showed that the administration of AGE precursors or AGEs increased ER stress and apoptosis in mice chondrocytes or human aortic endothelial cells [28,29]. In humans, elevated RAGE, ER stress marker glucose-regulated protein 78, and cell-cycle regulator p21 were all positively correlated with enhanced senescence-associated-β-galactosidase activity in patients with diabetic nephropathy [30].

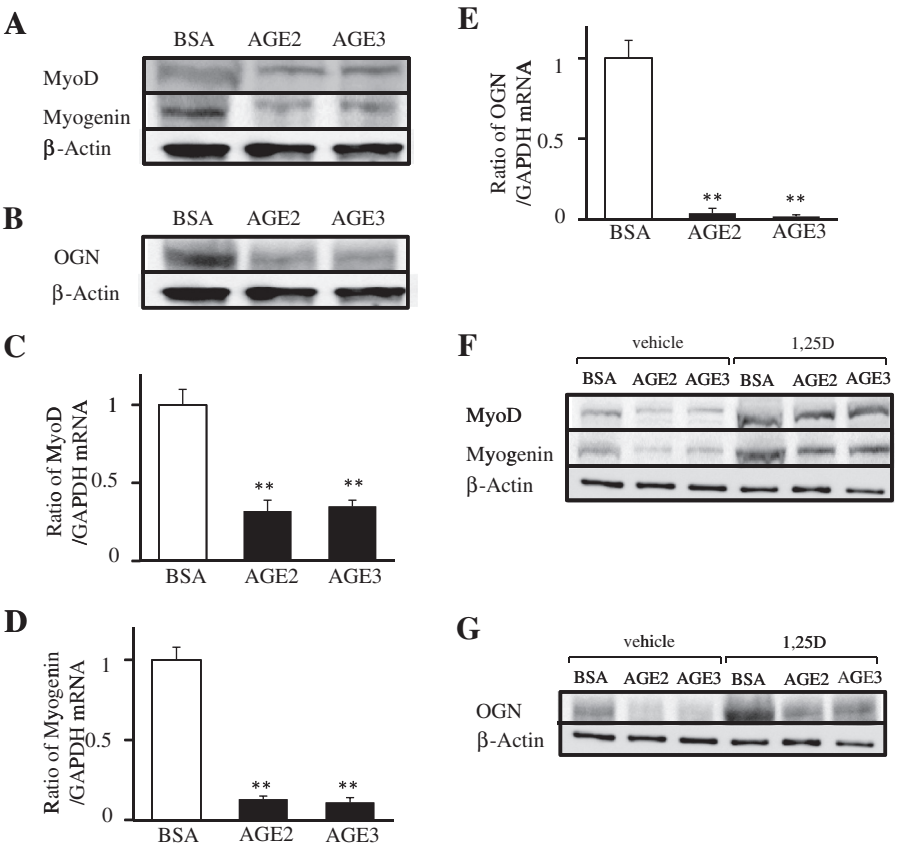

Fig. 4. AGEs suppressed the myoblastic differentiation and the expression of OGN in myoblastic cells, while 1,25D recovered the AGEs' effects. (A and B) Total proteins were extracted from 200 μg/mL AGE2- or AGE3-treated C2C12 cells after 48-h incubation. Western blot analysis was performed with anti-MyoD, myogenin, anti-OGN, or β-actin antibodies. (C-E) Total RNA was extracted from 200 μg/mL BSA-, AGE2-, or AGE3-treated C2C12 cells after 24-h incubation. Real-time PCR was performed and data were expressed as the GAPDH mRNA ratio. $^{**}P < 0.01$ relative to control. (F and G) Total proteins were extracted from 200 μg/mL BSA-, AGE2-, or AGE3-treated C2C12 cells after 48-h incubation with or without pretreatment of 10^{-10}M 1,25D for 24 h. Western blot analysis was performed with anti-MyoD, myogenin, OGN or β-actin antibodies.

In contrast, Riek et al. showed that vitamin D was a natural ER stress reliever that induced an anti-inflammatory monocyte/macrophage phenotype in type 2 diabetic patients [31,32]. Although further studies are needed to clarify the mechanism, AGEs and vitamin D might modulate the myoblastic differentiation and the expression of OGN through ER stress.

In this study, we found for the first time that vitamin D regulates OGN expression, leading to stimulate osteoblastic differentiation indirectly. However, to confirm our results, further experiments are necessary. We used C2C12 cells as a model for myoblastic cells because the cells are frequently used to examine the function and differentiation of myoblast *in vitro*. Although the cells were obtained by serial passage of myoblasts cultured from muscle tissue of C3H mice after a crush injury [33], they might not be identical to natural muscle cells *in vivo*. Therefore, we need further *in vivo* experiments and clinical studies in future. Furthermore, several molecules linking muscle to bone were previously reported. For example, we reported that Tmem119 is an important local inducer of muscle ossification [34], and that FAM5C acts as another humoral factor to stimulate osteoblastic differentiation [35]. Further studies focused on these would be interested.

In conclusion, 1,25D and ELD increased the differentiation of C2C12 cells and the expression of OGN, leading to the differentiation of MC3T3-E1 cells, suggesting that these agents might be useful to prevent and treat not only osteoporosis but also sarcopenia. Moreover, we found that, in contrast to active vitamin D, AGEs suppressed the myoblastic differentiation and the expression of OGN, suggesting that AGEs accumulation may be involved in sarcopenia and osteoporosis by suppressing myoblastic differentiation and OGN expression. In addition, 1,25D might be useful to prevent sarcopenia and osteoporosis by direct or indirect fashions through muscle tissues.

Conflict of interest

None of the authors has any conflict of interest.

Acknowledgments

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References

[1] C. Cooper, W. Dere, W. Evans, et al., Frailty and sarcopenia: definitions and outcome parameters, Osteoporos. Int. 23 (2012) 1839–1848.
[2] M.B. Snijder, N.M. van Schoor, S.M. Pluijm, et al., Vitamin D status in relation to one-year risk of recurrent falling in older men and women, J. Clin. Endocrinol. Metab. 91 (2006) 2980–2985.
[3] H.A. Bischoff, H.B. Stahelin, N. Urscheler, et al., Muscle strength in the elderly: its relation to vitamin D metabolites, Arch. Phys. Med. Rehabil. 80 (1999) 54–58.

[4] H.A. Bischoff-Ferrari, B. Dawson-Hughes, W.C. Willett, et al., Effect of Vitamin D on falls: a meta-analysis, JAMA 291 (2004) 1999–2006.
[5] H.A. Bischoff-Ferrari, B. Dawson-Hughes, H.B. Staehelin, et al., Fall prevention with supplemental and active forms of vitamin D: a meta-analysis of randomised controlled trials, BMJ 339 (2009) 3692.
[6] H. Okuno, K.N. Kishimoto, M. Hatori, et al., 1α,25-dihydroxyvitamin D_3 enhances fast-myosin heavy chain expression in differentiated C2C12 myoblasts, Cell Biol. Int. 36 (2012) 441–447.
[7] L.A. Garcia, K.K. King, M.G. Ferrini, et al., 1,25(OH)2vitamin D3 stimulates myogenic differentiation by inhibiting cell proliferation and modulating the expression of promyogenic growth factors and myostatin in C2C12 skeletal muscle cells, Endocrinology 152 (2011) 2976–2986.
[8] M. van Driel, M. Koedam, C.J. Buurman, et al., Evidence that both 1alpha,25-dihydroxyvitamin D3 and 24-hydroxylated D3 enhance human osteoblast differentiation and mineralization, J. Cell Biochem. 99 (2006) 922–935.
[9] E.M. Gardiner, P.A. Baldock, G.P. Thomas, et al., Increased formation and decreased resorption of bone in mice with elevated vitamin D receptor in mature cells of the osteoblastic lineage, FASEB J. 14 (2000) 1908–1916.
[10] H. Kaji, Interaction between Muscle and Bone, J. Bone Metab. 21 (2014) 29–40.
[11] H. Bentz, R.M. Nathan, D.M. Rosen, et al., Purification and characterization of a unique osteoinductive factor from bovine bone, J. Biol. Chem. 264 (1989) 20805–20810.
[12] K. Tanaka, E. Matsumoto, Y. Higashimaki, et al., Role of osteoglycin in the linkage between muscle and bone, J. Biol. Chem. 287 (2012) 11616–11628.
[13] P. Vestergaard, Discrepancies in bone mineral density and fracture risk in patients with type 1 and type 2 diabetes – a meta-analysis, Osteoporos. Int. 18 (2007) 427–444.
[14] R. Singh, A. Barden, T. Mori, et al., Advanced glycation end-products: a review, Diabetologia 44 (2001) 129–146.
[15] H. Vlassara, M.R. Palace, Diabetes and advanced glycation endproducts, J. Intern. Med. 251 (2002) 87–101.
[16] N. Ogawa, T. Yamaguchi, S. Yano, et al., The combination of high glucose and advanced glycation end-products (AGEs) inhibits the mineralization of osteoblastic MC3T3-E1 cells through glucose-induced increase in the receptor for AGEs, Horm. Metab. Res. 39 (2007) 871–875.
[17] K. Okazaki, T. Yamaguchi, K. Tanaka, et al., Advanced glycation end products (AGEs), but not high glucose, inhibit the osteoblastic differentiation of mouse stromal ST2 cells through the suppression of osterix expression, and inhibit cell growth and increasing cell apoptosis, Calcif. Tissue Int. 91 (2012) 286–296.
[18] K. Tanaka, T. Yamaguchi, H. Kaji, et al., Advanced glycation end products suppress osteoblastic differentiation of stromal cells by activating endoplasmic reticulum stress, Biochem. Biophys. Res. Commun. 438 (2013) 463–467.
[19] M. Yamamoto, T. Yamaguchi, M. Yamauchi, et al., Serum pentosidine levels are positively associated with the presence of vertebral fractures in postmenopausal women with type 2 diabetes, J. Clin. Endocrinol. Metab. 93 (2008) 1013–1019.
[20] S.S. Moon, Low skeletal muscle mass is associated with insulin resistance, diabetes, and metabolic syndrome in the Korean population: the Korea National Health and Nutrition Examination Survey (KNHANES) 2009–2010, Endocr. J. (2013) (Epub ahead of print).
[21] S.W. Park, B.H. Goodpaster, J.S. Lee, et al., Excessive loss of skeletal muscle mass in older adults with type 2 diabetes, Diabetes Care 32 (2009) 1993–1997.
[22] S.W. Park, B.H. Goodpaster, E.S. Strotmeyer, et al., Accelerated loss of skeletal muscle strength in older adults with type 2 diabetes: the health, aging, and body composition study, Diabetes Care 30 (2007) 1507–1512.
[23] H. Andersen, S. Nielsen S, C.E. Mogensen, et al., Muscle strength in type 2 diabetes, Diabetes 53 (2004) 1543–1548.
[24] M. Dalal, L. Ferrucci, K. Sun, et al., Elevated serum advanced glycation end products and poor grip strength in older community-dwelling women, J. Gerontol. A Biol. Sci. Med. Sci. 64 (2009) 132–137.
[25] K. Sun, R.D. Semba, L.P. Fried, et al., Elevated serum carboxymethyl-lysine, an advanced glycation end product, predicts severe walking disability in older women: the women's health and aging study I, J. Aging Res. (2012) (Epub ahead of print).
[26] M. Tanaka, K.N. Kishimoto, H. Okuno, et al., Vitamin D receptor gene silencing effects on differentiation of myogenic cell lines, Muscle Nerve 49 (2014) 700–708.
[27] G. Sorci, F. Riuzzi, C. Arcuri, et al., Amphoterin stimulates myogenesis and counteracts the antimyogenic factors basic fibroblast growth factor and S100B via RAGE binding, Mol. Cell Biol. 24 (2004) 4880–4894.
[28] S. Yamabe, J. Hirose, Y. Uehara, et al., Intracellular accumulation of advanced glycation end products induces apoptosis via endoplasmic reticulum stress in chondrocytes, FEBS J. 280 (2013) 1617–1629.
[29] C. Adamopoulos, E. Farmaki, E. Spilioti, et al., Advanced glycation end-products induce endoplasmic reticulum stress in human aortic endothelial cells, Clin. Chem. Lab. Med. 52 (2014) 151–160.
[30] J. Liu, K. Huang, G.Y. Cai, et al., Receptor for advanced glycation end-products promotes premature senescence of proximal tubular epithelial cells via activation of endoplasmic reticulum stress-dependent p21 signaling, Cell Signal. 26 (2014) 110–121.
[31] A.E. Riek, J. Oh, J.E. Sprague, et al., Vitamin D suppression of endoplasmic reticulum stress promotes an antiatherogenic monocyte/macrophage phenotype in type 2 diabetic patients, J. Biol. Chem. 287 (2012) 38482–38494.
[32] A.E. Riek, J. Oh, I. Darwech, et al., 25(OH) vitamin D suppresses macrophage adhesion and migration by downregulation of ER stress and scavenger receptor A1 in type 2 diabetes, J. Steroid Biochem. Mol. Biol. (2013) (Epub ahead of print).
[33] D. Yaffe, O. Saxel, Serial passaging and differentiation of myogenic cells isolated from dystrophic mouse muscle, Nature 270 (1977) 725–727.
[34] K. Tanaka, Y. Inoue, G.N. Hendy, et al., Interaction of Tmem119 and the bone morphogenetic protein pathway in the commitment of myoblastic into osteoblastic cells, Bone 51 (2012) 158–167.
[35] K. Tanaka, E. Matsumoto, Y. Higashimaki, et al., FAM5C is a soluble osteoblast differentiation factor linking muscle to bone, Biochem. Biophys. Res. Commun. 418 (2012) 134–139.