Update in vitamin D and multiple sclerosis

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ABSTRACT

Multiple sclerosis (MS) is a common neurological disease, and its etiology remains unknown. In recent years, increasing attention has been paid to the possible association between MS and vitamin D deficiency. Here, we review the current literature between MS and vitamin D, showing clear evidence that vitamin D deficiency is a risk factor for MS despite the lack of direct evidence for the effects of vitamin D in MS progression.

Multiple sclerosis (MS) is a chronic, inflammatory, and demyelinating disorder that affects the CNS. The estimated number of individuals with MS has increased from 2.1 million in 2008 to 2.3 million in 2013. Based on the 1975 Kurtzke classification, the Arabian Gulf Region is located in a low-risk zone for MS; however, recent studies suggest a moderate-to-high prevalence of MS in this region (31-55 MS patients per 100,000 individuals). The risk of MS is determined by genetic and environmental factors. One of the latter is vitamin D deficiency, which has attracted increased attention in the last decade. Entering the words “multiple sclerosis” and “vitamin D” as a PubMed search yields approximately 790 results in the last 10 years alone. Approximately one billion people worldwide have vitamin D deficiency or insufficiency. In a retrospective observational study of 10,709 patients in tertiary hospital clinics in Saudi Arabia, the prevalence of vitamin D deficiency was found to be 83.6%, which is high. The present article reviews the correlation between MS and vitamin D, considering updated studies from the literature.

Vitamin D metabolism. Vitamin D is a fat-soluble vitamin; its 2 main forms are ergocalciferol (vitamin D2), which is of plant origin, and cholecalciferol (vitamin D3), which is of animal origin. Vitamin D2 is considered less bioactive than vitamin D3. Vitamin D can be obtained from food, such as fatty fish, fortified foods, and vitamin supplements. However, the diet provides only a small percentage of human vitamin D intake, and the main source is skin exposure to sunlight. Total-body sun exposure easily provides the equivalent of 250 μg (10000 IU) vitamin D/d. In the skin, 7-dehydrocholesterol is photolyzed by ultraviolet radiation (UVR) from the sun and converted to pre-vitamin D3, which is isomerized to vitamin D3. The vitamin D binding protein transports vitamin D3 through the blood to the liver, where vitamin D is hydroxylated by one or more cytochrome P450 vitamin D 25-hydroxylases, resulting in the formation of 25-hydroxyvitamin D3 (25(OH)D3). Vitamin D status is reflected by serum levels of 25(OH)D3, which is the longest-living vitamin D metabolite (in terms of half-life). The 25(OH)D3 metabolite is further hydroxylated by renal CYP27B1 to 1,25-dihydroxyvitamin D [1,25(OH)2D; calcitriol], which is the most bioactive vitamin D metabolite.

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Vitamin D signaling is mediated by calcitriol binding to the vitamin D receptor, which forms a nuclear heterodimer with the retinoid X receptor. This complex is capable of binding to genomic vitamin D response elements, modulating the expression of a variety of genes.\(^1\) Also, like many other hormones, vitamin D can exert rapid actions at a cellular level (non-genomic effects), these actions are mediated within seconds to minutes.\(^13\) It is through these pathways that vitamin D modulates calcium hemostasis and performs its immunomodulatory functions.

**Vitamin D as an immunomodulator.** Vitamin D receptor expression has been reported in most immune cells,\(^14\) as well as in CNS tissues.\(^15\) Additionally, the rate-limiting enzyme for vitamin D synthesis, 25(OH)D3-1alpha-hydroxylase (CYP27B1), is expressed in immune cells. These cells are therefore, able to synthesize and secrete active vitamin D in both an autocrine and paracrine fashion,\(^16\) indicating that vitamin D plays a role in the immune system. The in vitro addition of 1,25-dihydroxyvitamin D3 (1,25(OH)2D3) to antigen-presenting cells (namely, monocytes, macrophages, and dendritic cells) inhibits the surface expression of major histocompatibility complex II-complexed antigens, and of costimulatory molecules, leading to reduced T cell stimulatory capacity. Additionally, 1,25(OH)2D3 directly exerts its immunomodulatory effects on T lymphocytes by inhibiting the production of Type 1 helper T cell cytokines (considered to be the key mediators in graft rejection and autoimmune diseases) and stimulating the production of Type 2 helper T cell cytokines, which have immunoregulatory functions.\(^17\) Furthermore, 1,25(OH)2D3 inhibits T cell and B cell proliferation and blocks B cell differentiation and immunoglobulin secretion. This compound also affects T cell maturation, inducing a shift away from the inflammatory T-helper 17 cells phenotype and facilitating the production of regulatory T cells.\(^18\) All of these immunomodulatory effects of 1,25(OH)2D3 can lead to the protection of target tissue in autoimmune diseases and transplantation. However, experimental studies have reported that the observed immunomodulatory effects of vitamin D only occur at hyper-physiologic concentrations, which causes hypercalcemia in humans.\(^17\) Therefore, the development of novel vitamin D analogs that have immunosuppressive effects, but do not cause significant hypercalcemia is required. Many clinical trials have been, or are currently being conducted to test the therapeutic application of vitamin D or its analogs in inflammatory processes.\(^19\)

**Vitamin D and MS risk.** It is well known that MS is more prevalent in higher latitudes, where sunlight is of lower intensity than in lower latitudes. Recent meta-analyses\(^20\) supported a latitude gradient in MS prevalence. Several recent studies found that increased body exposure to sunlight, and hence a decreased susceptibility to vitamin D deficiency, is also associated with a decreased risk of MS.\(^21\)–\(^26\) especially if the sun exposure occurred during childhood and adolescence. Studies have also shown that the birth month is correlated with MS risk; individuals born in the fall (namely, whose mothers were exposed to summer sunlight) have a low MS risk, whereas individuals born in the spring have a higher risk of MS. This observation indicates the presence of an association among maternal sunlight exposure during pregnancy, vitamin D status, and the risk of MS. In 2013, a systematic review\(^27\) analyzed published data on the effects of birth month for 151,978 MS patients born in the Northern Hemisphere. The results of this analysis demonstrated a significant increase of MS risk among individuals who were born in April and a reduction in risk in people who were born in October and November. However, sunlight also has an immunosuppressive effect,\(^28\) and UVR was recently found to suppress experimental autoimmune encephalomyelitis.\(^29,30\) Therefore, the effects of sunlight on MS risk could be related to sunlight itself; instead of vitamin D. Studies that evaluate either serum vitamin D levels or vitamin D intake, are needed to determine whether vitamin D deficiency is a risk factor for MS independent of sun exposure. The strongest evidence in this regard came from a large prospective case-control study\(^31\) of more than 7 million US military personnel from whom serum samples were obtained before any appearance of MS symptoms. This study concluded that, among Caucasians, there was a 41% decrease in MS risk for every 50-nmol/L increase in 25-hydroxyvitamin D; the effect was stronger for samples taken before the age of 20. Another case-control study\(^32\) prospectively collected blood samples from 192 MS patients and showed that serum 25-hydroxyvitamin D (25(OH)D) levels ≥ 75 (versus < 75) nmol/L in the blood were associated with a 61% decrease in the risk of MS. A recent study concluded that sun exposure and vitamin D status independently affect the risk of MS.\(^24\) Vitamin D intake and the risk of developing MS were assessed in a large prospective cohort that included approximately 200,000 women.\(^33\) In this study, the incidence of MS was 41% lower among women with a vitamin D intake of ≥ 400 IU/day, compared with women who did not take supplements.\(^33\) Another 2 studies concluded that the intake of fatty fish was associated with a decreased risk of MS, even at higher latitudes.\(^34,35\) Mirzaei et al\(^36\) studied a large cohort and analyzed the association...
between maternal milk intake, maternal dietary vitamin D intake, and predicted maternal serum 25(OH)D during pregnancy and their daughters’ risk of developing MS. The study showed that the relative risk of MS was significantly lower in women whose mothers had high milk or vitamin D intake during pregnancy than in women born to low-intake mothers.36 However, another study of a large cohort of US women showed that total vitamin D intake during adolescence was not associated with the risk for MS in adulthood.37 In addition, 25(OH)D levels during the neonatal period were not associated with the risk of MS in a large population-based case-control study.38 This data may support the hypothesis that vitamin D consumption throughout an individual’s entire lifespan, rather than over a short period of time, may contribute to the risk of MS.

**Vitamin D and disease progression in MS.** Several studies have shown that vitamin D levels are lower in MS patients than in controls.39-44 A recent study45 showed that in clinically isolated syndrome patients (namely, those suffering a single demyelinating attack that is compatible with MS), vitamin D deficiency was a predictor of developing clinically definite MS. The association of disease activity with vitamin D levels in MS patients has been evaluated in multiple studies that demonstrated a lower MS relapse rate in patients with higher levels of vitamin D.46-49 Additionally, low levels of vitamin D appear to be associated with high levels of disability41,47-52 as measured by the Expanded Disability Status Scale (EDSS). The EDSS is a commonly used index of clinical disability in MS, with scores ranging from 0 (corresponding to a normal examination and function) to 10 (for death due to MS). Two recent studies conducted in 2014 support this association. In the first study,53 181 patients were prospectively followed, and EDSS scores were correlated with plasma vitamin D levels. Patients with vitamin D levels >50-nmol/L were 2.78 times more likely to have an EDSS <4 (p=0.0011). The second study54 was originally designed to evaluate the impact of early versus delayed interferon beta-1b treatment in patients with clinically isolated syndrome. Serum 25(OH)D concentrations were measured at baseline and at 6, 12, and 24 months. Patients were followed for 5 years with clinical assessments and MRI. A 50-nmol/L increase in average serum 25(OH)D levels within the first 12 months predicted a 57% lower treatment rate of new active lesions (p<0.001), a 57% lower relapse rate (p=0.03), and a 25% lower yearly increase in T2 lesion volume (p<0.001) from months 12 to 60. Levels ≥50 nmol/L at follow-periods of up to 12 months predicted lower EDSS scores (p=0.004) during the subsequent 4 years.54 Observational studies correlating vitamin D levels to MS severity cannot prove that increased sun exposure alleviates the symptoms of MS, especially given that severely disabled patients with MS receive less sun exposure, which can cause vitamin D deficiency. Even MS patients who are fully mobile are theoretically more susceptible to vitamin D deficiency because they avoid sun exposure, worsening their symptoms. Therefore, establishing the effects of vitamin D on disease activity and severity in MS patients requires randomized controlled trials (RCTs). Table 1 summarizes interventional studies in which MS patients received vitamin D supplementation.55-66 As shown in Table 1, none of the RCTs demonstrated a significant reduction in relapse rate or EDSS in response to vitamin D supplementation. In one RCT, a significant decrease in T1-enhancing lesions was seen in the treatment group. Multiple studies have demonstrated favorable immunological changes in the serum of MS patients in the treatment group. However, none of the RCTs listed in Table 1 were sufficiently powered to observe a treatment effect. Therefore, we cannot conclude that vitamin D is a clinically effective treatment for MS patients; however, we can conclude that a high dose of vitamin D is safe in the short term. Approximately 6 large RCTs are ongoing; the results of these analyses will provide solid evidence regarding the benefits of vitamin D supplementation.

**Vitamin D, genetics, and MS.** The increase in the concordance ratio for MS risk between mono- and dizygotic twins with increasing latitude suggests that genetic effects may be stronger for individuals with low concentrations of vitamin D.67 The Wellcome Trust Case Control Consortium and the International MS Genetics Consortium completed the largest MS genome-wide association study68 and identified 2 genes involved in vitamin D metabolism that could increase susceptibility to MS. The first is CYP27B1, which encodes a rate-limiting enzyme for vitamin D synthesis. The second is CYP24A1, which encodes an enzyme that degrades 1,25-dihydroxyvitamin D. It is likely that these genes contribute to MS risk by decreasing the levels of active vitamin D. In addition, the RNA expression level of the major MS susceptibility gene HLA-DRB1*15:01 (the strongest genetic predictor of MS risk) is regulated by vitamin D. Furthermore, vitamin D receptor-binding elements have been identified in the majority of MS-associated genes, indicating that the expression of many of these genes may be regulated by vitamin D.69

In conclusion, it is clear from observational studies that vitamin D deficiency is a modifiable risk factor
### Table 1 - Summary of vitamin D interventional studies that have been carried out in multiple sclerosis patients.

| Study date            | Study type          | Vitamin D dose, size, and duration of the study                                                                 | Clinical results                                                                                                           | Radiological results                                                                                                      | Laboratory results                                                                                                      |
|-----------------------|---------------------|---------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|
| Mosayebi et al, 2011  | RCT                 | A total of 62 MS patients enrolled; treatment group received 300,000 IU/month vitamin D3 as IM injection for 6 months | No significant difference in EDSS between the treatment and control group                                                  | No significant difference in the number of gadolinium-enhancing lesions between the treatment and control group         | Levels of cell proliferation in the treatment group were significantly lower than in the control. The TGF-beta and INL-10 treatment groups were significantly higher than in the controls |
| Wingerchuk et al, 2005 | Open-label pilot study | Fifteen MS patients received oral calcitriol (target dose: 2.5 mcrog/d) for 48 weeks. Dietary calcium was restricted to 800 mg/d | The on-study exacerbation rate (27%) was less than baseline. Two patients withdrew because of symptomatic hypercalcaemia upon discontinuation of calcitriol at 12 months. The EDSS increased to 3.1 | Brain MRI revealed enhancing lesions in 5 patients at baseline (33%), and in 4 (29%) at both 24 and 48 weeks |                                                                                                                          |
| Soilu-Hänninen et al, 2012 | RCT                 | Total of 66 MS enrolled; treatment group received 20000 IU/week vitamin D3 as an add-on therapy to interferon β-1b for over one year | Tendency for reduced disability accumulation ($p=0.071$). No significant differences in adverse events or in the annual relapse rate | Significantly lower number of T1-enhancing lesions in the treatment group ($p=0.004$)                                      |                                                                                                                          |
| Kimball S et al, 2011  | RCT                 | Total of 49 patients enrolled; treatment group received increasing doses of cholecalciferol (4,000-40,000 IU/d) plus calcium (1,200 mg/d), followed by 10,000 IU/d over one year | In the placebo group, the mean EDSS increased from 1.70 at baseline to 1.94 at the end of the study ($p<0.01$). Average EDSS and RR at the end of the trial did not differ between the 2 groups. The EDSS was higher following high-dose D2 than following low-dose D2 ($p=0.05$). There were 4 relapses with high-dose D2 versus none with low-dose D2 ($p=0.04$) | Abnormal T cell reactivities were suppressed in vivo by cholecalciferol at serum 25(OH)D concentrations higher than 100 nmol/L |                                                                                                                          |
| Shaygannejad et al, 2012 | RCT                 | Total of 50 patients enrolled; treatment group received escalating calcitriol doses up to 0.5 μg/day over one year | No significant treatment differences were detected in the primary MRI endpoints                                              |                                                                                                                          |                                                                                                                          |
| Stein et al, 2011     | RCT                 | A total of 23 MS patients; treatment group received high-dose vitamin D2 (6,000 IU) over 6 months. All received daily low-dose (1,000 IU) D2 to prevent deficiency | No significant adverse events occurred. Non-significant reduction in RR and EDSS in the treatment group                   |                                                                                                                          |                                                                                                                          |
| Burton et al, 2010    | RCT                 | A total of 49 MS patients enrolled in the 52-week trial; treatment group received escalating vitamin D doses up to 40,000 IU/day over 28 weeks, followed by 10,000 IU/day (12 weeks), and further down titrated to 0 IU/day; calcium (1,200 mg/day) was given | No significant adverse events occurred. Non-significant reduction in RR and EDSS in the treatment group                   |                                                                                                                          |                                                                                                                          |

MS - multiple sclerosis, IM intramuscular, EDSS - Expanded Disability Status Scale, RR - relapse rate, TGF - transforming growth factor, INL - interleukin, 25(OH)D - 25-hydroxyvitamin D, ON - optic neuritis, ARR - annualized relapse rate, RCT - randomized controlled trials
for MS. Therefore, persons who are at risk for MS (for example, first-degree relatives of MS patients, or patients with a single episode demyelinating attack) should be screened for vitamin D deficiency. As stated previously, evidence for the effect of vitamin D on disease progression is lacking, but it is known that MS patients have an increased prevalence for vitamin D deficiency (due to for example, immobility, sun avoidance, corticosteroids, and anti-epileptic use). These patients are also susceptible to osteoporosis. Therefore, vitamin D levels should be determined, and deficiency should be treated. The optimal serum vitamin D levels for exerting immunomodulatory effects have not been clinically established. Based on bone health criteria, the US and Canadian Institute of Medicine (IOM) recently stated that individuals are vitamin D sufficient at 25OHD levels ≥ 50 nmol/L; levels above 75 nmol/L have not consistently been associated with an increased benefit. Although risks have been identified for some outcomes at levels above 125 nmol/L, it has been suggested that up to 4000 IU/day of vitamin D intake is unlikely to cause toxicity, even in healthy individuals. Some experts favor maintaining 25(OH)D levels between 75 to 125 nmol/L in MS patients, as these levels are still within the safe range of the IOM report, and immunomodulatory effects have been observed in hyper-physiologic ranges in experimental studies. However, the long-term effects of such high levels are unknown.

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