Vitamin D in the Foot and Ankle

A Review of the Literature

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Background: Vitamin D is an essential vitamin that targets several tissues and organs and plays an important role in calcium homeostasis. Vitamin D deficiency is common, particularly at higher latitudes, where there is reduced exposure to ultraviolet B radiation. We reviewed the role of vitamin D and its deficiency in foot and ankle pathology.

Methods: The effects of vitamin D deficiency have been extensively studied, but only a small portion of the literature has focused on the foot and ankle. Most evidence regarding the foot and ankle consists of retrospective studies, which cannot determine whether vitamin D deficiency is, in fact, the cause of the pathologies being investigated.

Results: The available evidence suggests that insufficient vitamin D levels may result in an increased incidence of foot and ankle fractures. The effects of vitamin D deficiency on fracture healing, bone marrow edema syndrome, osteochondral lesions of the talus, strength around the foot and ankle, tendon disorders, elective foot and ankle surgery, and other foot and ankle conditions are less clear.

Conclusions: Based on the available evidence, we cannot recommend routine testing or supplementation of vitamin D in patients with foot and ankle pathology. However, supplementation is cheap, safe, and may be of benefit in patients at high risk for deficiency. When vitamin D is supplemented, the evidence suggests that calcium should be co-supplemented. Further high-quality research is needed into the effect of vitamin D in the foot and ankle. Cost-benefit analyses of routine testing and supplementation of vitamin D for foot and ankle pathology are also required. (J Am Podiatr Med Assoc 110(3): 1-11, 2020)

Vitamin D is an essential vitamin. Its active form in the human body is 1,25-dihydroxyvitamin D. It targets specific vitamin D receptors that modify the expression of more than 200 genes in at least 36 different tissues throughout the body.[1] Apart from its well-known role in calcium homeostasis, it has various musculoskeletal, neuromuscular, and immune functions.[1-7] Its musculoskeletal targets include bone, bone marrow, cartilage, muscle, and osteoblasts.[8-10] Its neuromuscular effects include increasing muscle strength and contractility, improving calcium handling, and increasing calmodulin synthesis.[4,11] Its immunologic effects include regulation of both cell-mediated and humoral immunity. Vitamin D has targets in B lymphocytes and CD4 T lymphocytes, affecting antibody production and immune response. It also regulates CD8 T lymphocytes, which may play a role in suppressing autoimmunity.[5] Figure 1 summarizes the production and actions of vitamin D in the body.

In many regions of the world, vitamin D deficiency is thought to afflict a significant proportion of the population.[12,13] There are three sources of vitamin D: exposure to sunlight, natural diet, and dietary supplements. Vitamin D is manufactured in the skin on exposure to direct sunlight: ultraviolet B radiation (UVR) converts 7-dehydrocholesterol to pre–vitamin D_3, which, in turn, is either metabolized in the liver to 25-hydroxyvitamin D (25[OH]D) or stored.[3,9,13] Most adults do not obtain enough vitamin D from sunlight alone; there is no safe dose of UVR that can provide adequate vitamin D production without a significantly increased risk of skin cancer.[14] Dietary supplementation is, therefore,

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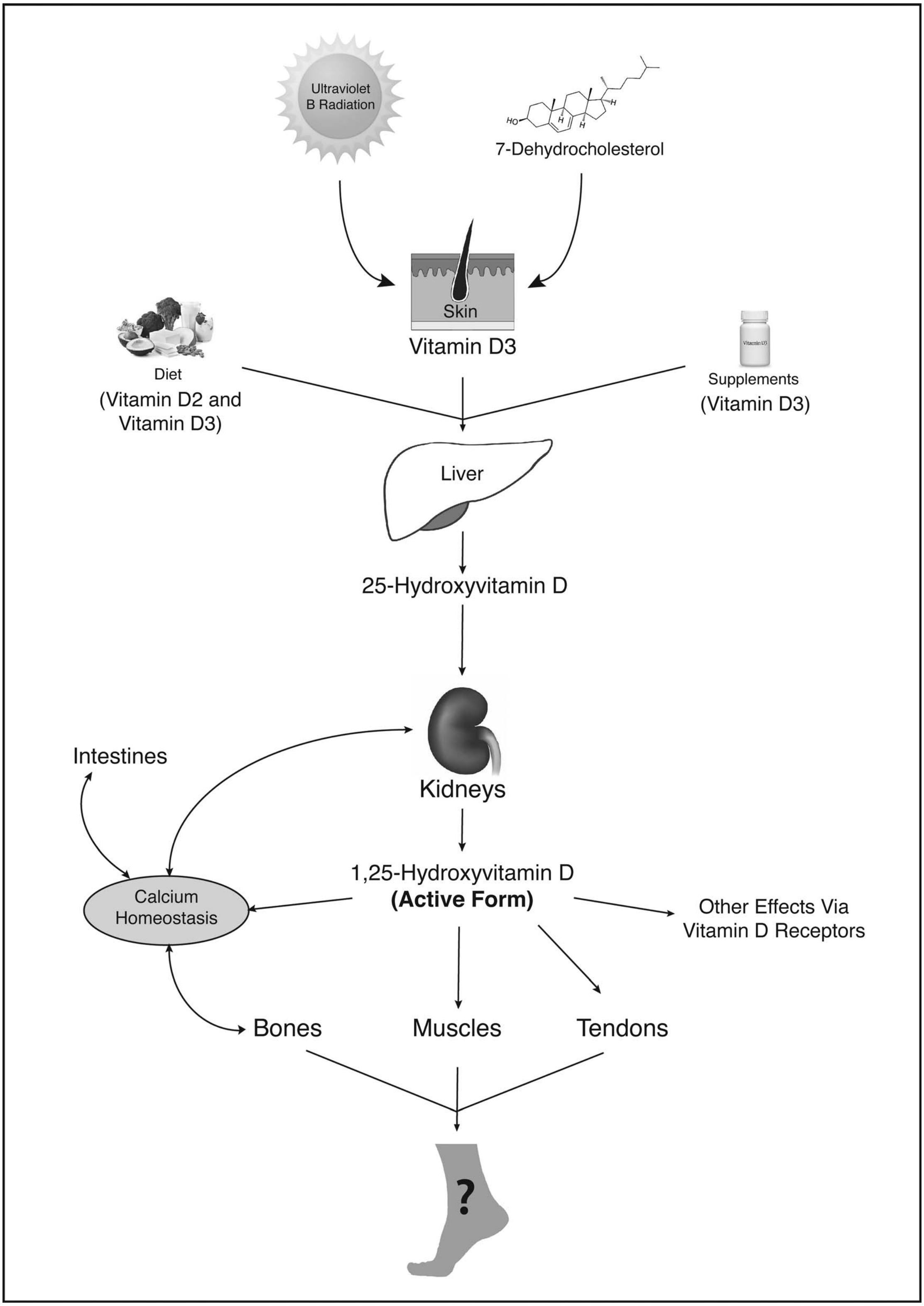

Figure 1. The stages of vitamin D production in the human body and its various targets.

essential; this requires a balanced diet with food high in vitamin D, and in many countries, cereals and foods are fortified with vitamin D.[15] Despite this, patients in higher latitudes are still at risk for deficiency and may require additional supplementation.

During the past decade vitamin D deficiency and its varied effects, particularly in calcium homeostasis and bone health, have been increasingly recognized, and supplementation has been recommended by a variety of national and international bodies.[13,14,16] Its role in osteoporosis and fractures has been well established, and numerous studies have examined levels of vitamin D in fracture healing and other musculoskeletal pathology.[4,10,11,17-22] However, the role of vitamin D in pathology of the foot and ankle has been less extensively studied. A variety of Web sites, Internet forums, and even comments in journals suggest a relationship between vitamin D deficiency and a variety of foot and ankle disorders, such as plantar fasciitis.[23] However, these purported links are often unreferenced or based on anecdote, and vitamin D has not been definitively linked to most foot and ankle conditions.

In this article we review the literature on vitamin D and its deficiency, particularly regarding pathology of the foot and ankle. We present the available evidence to highlight areas of ongoing research and areas with deficient research and attempt to draw conclusions regarding the need for routine testing and supplementation of vitamin D in the foot and ankle population.

Methods

For this study we performed a review of the literature by searching multiple databases, including PubMed, MEDLINE, and Ovid Online. The search was restricted to fully published articles written in the English language and pertaining to humans. We searched for the key words *vitamin D* paired with *foot*, *ankle*, *stress fractures*, *diabetic foot*, *bone marrow edema syndrome*, *talus*, *tendon*, and *plantar fasciitis*. The articles were screened for eligibility and clinical relevancy based on title and abstract. Papers were excluded if they did not actually pertain to the search criteria; if they were for opinion articles, letters, or commentaries; or if they were purely basic science papers. For papers deemed eligible for inclusion, the full papers were obtained. Papers were considered to have met the inclusion criteria if they were prospective or retrospective studies examining the relationship between vitamin D and the foot and ankle. Further cross referencing was performed if the included papers referenced relevant articles not picked up by the initial search criteria. Figure 2 is a flow diagram of the results of the search criteria.

On review of the literature it became apparent that there was a substantial paucity of data and significantly varied methods among the small number of studies. Furthermore, most studies pertaining to the foot and ankle included only a small number of patients, were retrospective studies, and comprised level IV evidence, precluding any in-depth analysis. We present the currently available literature to highlight our current understanding and areas for further research. We also present a summary of current concepts in vitamin D deficiency and its systemic effects to put into context the available data in the foot and ankle setting.

Results

Vitamin D Deficiency

Vitamin D deficiency is a global health problem thought to affect up to 1 billion people worldwide.[13,24] There is significant geographic and seasonal variation in the prevalence of vitamin D deficiency: it is more prevalent in higher latitudes and in the winter months due to decreased UVR,[25] where up to 50% of the adult population may be deficient.[12,13] There is ongoing debate about what the threshold for classifying deficiency should be. The threshold currently used for diagnosing deficiency in the United Kingdom is less than 25 nmol/L (for conversion to μg/L, divide by 2.5). This is the lower limit, below which evidence suggests that the risk of rickets in children and of osteomalacia in adults increases.[14] The Department of Health and Social Care in the United Kingdom recommends that serum 25(OH)D levels be maintained above this level.[26] The Endocrine Task Force Group states that 25(OH)D levels of 30 to 50 nmol/L are thought not to affect bone health but may affect other tissues, including muscle metabolism.[27] In the United States, the National Institutes of Health (NIH) recommends that vitamin D levels greater than 50 nmol/L may be considered sufficient, levels of 30 to 50 nmol/L are insufficient for bone and overall health, and levels less than 30 nmol/L are deficient and associated with risk of rickets/osteomalacia.[15]

Other groups calculate deficiency differently, by determining the level of 25(OH)D at which the concentration of immunoreactive parathyroid hormone begins to rise. Using this definition, deficiency

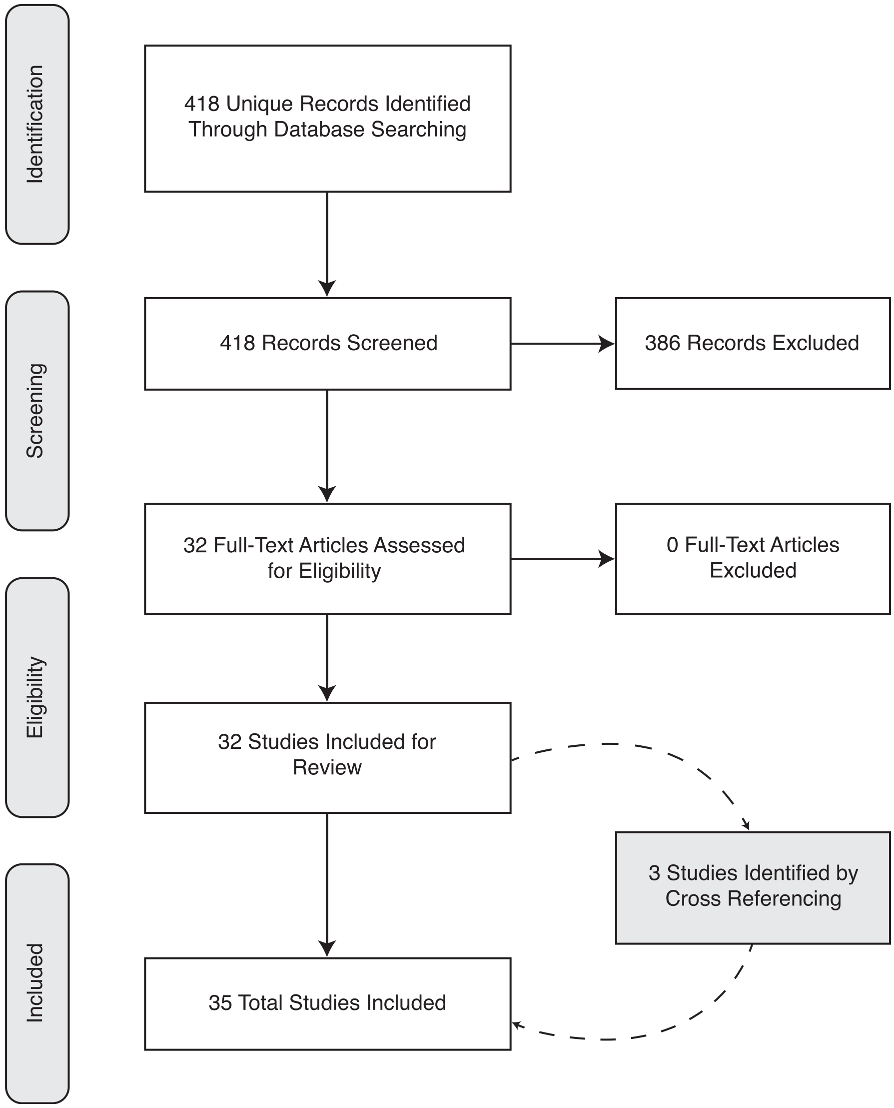

Figure 2. Flow diagram of the papers identified through applying the search criteria and the papers finally included.

has been defined as less than 50 nmol/L and insufficiency between 50 and 75 nmol/L.[28] These values are defined for adults because vitamin D levels are not routinely measured in children and so it is difficult to identify definite thresholds for treatment.[14] Table 1 highlights the varying definitions of vitamin D deficiency.

Various studies use differing definitions of vitamin D deficiency in their analysis and grouping of patients, which makes direct comparisons between studies difficult. Regardless of cutoff values, vitamin D deficiency is prevalent in patients undergoing orthopedic surgery. Authors at similar latitudes (39°N to 40°N) have found a wide variation in the prevalence of vitamin D deficiency in their elective surgery patients: 17% to 81% when deficiency is defined as less than 50 nmol/L (level of evidence: IV [for both studies]).[29,30] Other authors have found that 67% to 83% of their elective foot and ankle surgery patients had vitamin D deficiency (<75 nmol/L) at latitudes 44.5°N to 52.3°N (level of evidence: IV [for both studies]).[31,32]

General Effects of Vitamin D Deficiency. Vitamin D deficiency has health implications for pregnancy and lactation, childhood growth, cancer, cardiovascular disease, cerebrovascular disease, immune modulation, autoimmune disease, multiple sclerosis, age-related macular degeneration, rheumatoid arthritis, systemic lupus erythematous, cognition, depression, and schizophrenia.[4,5,33] The

Table 1. Differing Definitions of Vitamin D Sufficiency/Deficiency

Vitamin D Status	Level of 25-Hydroxyvitamin D (nmol/L [μg/L]) Based on Bone Health[14,15]	Based on iPTH Levels[27]
Sufficient	>50 (>20)	>75 (>30)
Insufficient	30–50 (12–20)	50–75 (20–30)
Deficient	<30 (<12)	<50 (<20)

Note: Patients who were considered vitamin D replete using the definition laid out by the Global Consensus Recommendations on Prevention and Management of Nutritional Rickets[14] and the National Institutes of Health[15] may be considered insufficient by measurement of iPTH levels.[28]

Abbreviation: iPTH, immunoreactive parathyroid hormone.

literature is frequently inconsistent and consists of observational studies or randomized controlled trials that are often inconclusive.[26] However, vitamin D deficiency has been shown to predispose to infections (level of evidence: IV),[33,34] and a meta-analysis has demonstrated that supplementation of vitamin D can help prevent respiratory infection, particularly in those severely deficient (<25 nmol/L) (level of evidence: II).[35] There is, therefore, good-quality evidence to support the role of vitamin D supplementation in the prevention of respiratory infections.

The Musculoskeletal System. There is an established evidence base for the benefits of vitamin D supplementation in childhood, specifically regarding rickets, osteomalacia, muscle strength, and falls.[10,26,36] Vitamin D is important in preventing nutritional rickets[14] and osteomalacia.[37] It also acts on muscles via vitamin D receptors and enzyme CYP27B1 (1-alpha-hydroxylase).[4] Higher levels of vitamin D have been found to improve muscle function and increase the relative number and size of type 2 muscle fibers.[8,36] Correcting vitamin D deficiency can reverse associated muscle weakness.[17] Vitamin D supplementation is also beneficial in reducing risk of falls through its effect on muscle strength.[13,36,38] Severe vitamin D deficiency has been associated with generalized musculoskeletal pain in adults,[19] but the same may not hold true in children.[39]

Vitamin D supplementation has been shown in animal models to promote bone healing and callus formation, and deficiency has been shown to impair bony healing.[9,40] There are corollaries in human clinical studies, where daily supplementation of 800 IU of vitamin D and 1 g of calcium has been shown in a randomized controlled trial to increase early callus formation in proximal humeral fractures (level of evidence: II).[41] There is also a suggestion that deficiency may increase time to union in spinal fusion (level of evidence: IV).[42] However, vitamin D deficiency and supplementation has not, in itself, been shown to alter the risk of nonunion of fractures.[20,21,43] A meta-analysis has similarly failed to demonstrate overall significant benefit to fracture healing when a cutoff value of 75 nmol/L was used to define insufficiency (level of evidence: II).[18]

A prospective longitudinal study looking at adolescent girls demonstrated a higher rate of stress fractures in participants with lower vitamin D levels (level of evidence: III).[44] A Cochrane review has suggested that supplementation of vitamin D and calcium may reduce the risk of stress fractures, particularly in the older age group (level of evidence: II).[45] These findings have been corroborated by several military studies (level of evidence: II).[46,47]

Bischoff-Ferrari et al[22] performed a meta-analysis of 31,022 patients with fractures and found that there was a nonsignificant 10% reduction in future hip fracture and a 7% reduction in nonvertebral fractures when taking 800 IU of vitamin D daily (level of evidence: II). A systematic review attempted to determine whether vitamin D deficiency was associated with poorer outcome after non–foot and ankle orthopedic surgery. Most studies included in their review were methodologically flawed, but the authors concluded that taken together it suggested that vitamin D deficiency may be associated with nonspecifically reduced outcomes of surgery (level of evidence: III).[48]

The evidence, therefore, supports co-supplementation of vitamin D (800 IU per day) and calcium in patients with deficiency to prevent rickets/osteomalacia, improve muscle strength, reduce the risk of falls and fractures in the elderly, and reduce the risk of stress fractures. Further work is required to determine whether supplementation improves fracture healing.

Diabetes and the Diabetic Foot. Vitamin D has also been studied in the context of diabetes mellitus. Soderstrom et al[6] examined vitamin D levels in diabetic neuropathy and found that vitamin D can help improve pain in this setting (level of evidence: III). They speculated that the effect may have been a result of the effect of vitamin D concentration on calcium levels. However, there are also associations between glycemic control and vitamin D, and it was not clear whether increased levels of vitamin D were simply a marker of improved health (level of evidence: IV).[6,49] Yoho et al[50] examined levels of vitamin D in healthy patients versus patients with longstanding diabetes. Although their entire population group had vitamin D insufficiency, the degree of insufficiency was greater in the diabetic group (level of evidence: III).[50] There was no difference, however, between vitamin D level and presence or absence of Charcot's neuro-arthropathy in diabetic patients.[50]

Other studies have examined diabetic foot infections and found that lower levels of vitamin D were associated with higher infection and ulcer rates.[7,51,52] Tiwari et al[51] found that the infection rate was four times higher in deficiency of vitamin D and hypothesized that this may be due to immune cell suppression (level of evidence: III). However, because these were all retrospective comparative studies, none of these papers could ascertain that it was, indeed, the vitamin D deficiency that resulted in the increased infection rate rather than other confounding factors, such as glycemic control and neuropathy. Conversely, Afarideh et al[34] found higher vitamin D levels in patients with diabetic foot ulcers, but their entire study population was vitamin D deficient, which is a significant confounding factor (level of evidence: III).

The currently available evidence demonstrates that vitamin D deficiency is prevalent in patients with diabetic foot disease and suggests that lower levels are associated with increased risk of infection and ulceration. However, the evidence is insufficient to determine whether supplementation alters outcome, and further work is required in this area.

Fractures Around the Foot and Ankle. Vitamin D is known to help prevent fractures[22]; however, whether supplementation of vitamin D improves fracture healing is less clear. One study reports a high prevalence (84%) of endocrine abnormalities in patients with unexplained fracture nonunions (level of evidence: IV),[43] yet no difference in vitamin D deficiency prevalence was found between groups with impaired bone union and normal fracture healing in two other studies (level of evidence: III [for both studies]).[20,21]

Vitamin D insufficiency seems common in low-energy fractures. Smith et al[53] compared patients with low-energy foot and ankle fractures and patients with ankle sprains and found vitamin D levels to be significantly lower in the fracture group (level of evidence: III). They also found that the fracture risk in vitamin D deficiency increased with smoking, obesity, and other medical risk factors.[53] In contrast, another prospective study that compared metatarsal fractures with ankle sprains found that vitamin D levels were similarly low between the two groups and concluded that vitamin D levels cannot predict risk of metatarsal fractures (level of evidence: III).[54] Clutton and Perera[55] reported on 40 fifth metatarsal fractures and found that only 35% had sufficient vitamin D levels (>50 nmol/L) (level of evidence: IV). However, there was no control group, and, therefore, causality cannot be inferred from this study. Finally, Shimasaki et al[56] performed a retrospective study of 37 football players with injuries and concluded that a lower vitamin D level correlated with an increased risk of metatarsal stress fractures after controlling for age and body mass index (level of evidence: III).

There are a plethora of case reports attributing fracture healing to vitamin D supplementation (level of evidence: V).[57] However, few of these prove causation, and the evidence base for appraising the role of vitamin D in foot and ankle fractures lacks randomized controlled trials in humans and instead relies heavily on level IV evidence and animal studies (level of evidence: IV).[58] Although vitamin D deficiency does seem to be associated with increased risk of fractures, it is unclear whether this is the cause or a reflection of some other deficiency.

Osteochondral Lesions of the Talus. Telleria et al[59] compared patients presenting with osteochondral lesions of the talus and patients with ankle sprains in the summer months over a 9-year period (level of evidence: III). They found a statistically significant difference in vitamin D levels between the groups, with deficiency being far more common in the osteochondral lesions of the talus group. This study does have a few limitations, however. They used the more stringent cutoff value for low vitamin D level (<75 nmol/L), and if their data are analyzed with reference to values of 50 nmol/L then the difference is no longer statistically significant. Furthermore, their ankle sprain group was older by 12.6 years. Finally, it is not clear how vitamin D levels affected their later outcomes and, therefore, we cannot assess the benefit of vitamin D supplementation in these patients.

Strength Around the Foot and Ankle. The evidence for the role of vitamin D in foot and ankle strength is unclear. Bird et al[60] performed a study with 88 older adult patients and found a seasonal variation in vitamin D of 15%, a seasonal variation in physical activity of 13%, and a seasonal variation in ankle dorsiflexion strength of 8%, although quadriceps strength stayed the same (level of evidence: IV). They performed a regression analysis and found that both age and season correlated to ankle strength. The vitamin D levels peaked 4 weeks later than other variables, which is likely due to the time needed for 25(OH)D to be formed after increasing sunlight exposure.[60] This does, however, suggest that the increase in strength was seen due to the increased activity in warmer weather rather than the increased level of vitamin D, which came later. The authors acknowledge this and further highlight that most falls occurred in the winter due to trips, which they speculate may be linked to inability to clear obstacles on account of weaker ankle dorsiflexion, but cannot attribute this to vitamin D deficiency.[60]

In another study involving 20 patients with type 2 diabetes mellitus, no significant relationship was found between ankle plantarflexion strength and vitamin D (level of evidence: IV [for results regarding vitamin D]).[61] Therefore, the evidence linking vitamin D levels and strength around the foot and ankle is not of sufficient quality to be able to draw any firm conclusions regarding its effects and the need for monitoring or supplementation.

Tendons and Soft Tissues Around the Foot and Ankle. Vitamin D may have a role in tendon healing[2]; however, there is a lack of high-quality evidence available to assess this. Although not specific to the foot and ankle, there have been case reports of spontaneous bilateral quadriceps tendon ruptures in patients with secondary hyperparathyroidism (either due to renal dialysis or vitamin D deficiency) (level of evidence: V).[62,63] In these series, however, there was no histologic analysis to confirm the pathology, and it is not possible to conclude that it was the vitamin D deficiency that caused the ruptures.

There is currently only one study looking at the role of vitamin D in plantar fasciitis and Achilles tendinopathy. In this retrospective series, the authors found that very low vitamin D levels (<15 nmol/L) and hyperparathyroidism correlated with an increased incidence of plantar fasciitis in children (level of evidence: IV [for role of vitamin D]).[64] The study was performed at a rheumatology clinic, so there may have been other relevant comorbidities, and it is not clear whether the findings are due to vitamin D deficiency, some other deficiency, or parathyroid hormone excess. In looking at subclinical Achilles tendon enthesopathy in patients with inflammatory bowel disease, Kimyon et al[65] found no association between vitamin D and tendon enthesopathy in a sample of 100 patients (level of evidence: III). There is, therefore, insufficient evidence to confirm whether vitamin D deficiency plays a role in plantar fasciitis or Achilles tendinopathy and whether supplementation can affect the outcome of these conditions.

Outcome of Foot and Ankle Surgery. The evidence for the role of vitamin D in elective foot and ankle surgery is inconclusive. Moore et al[66] conducted a retrospective case-control study into the risk factors for nonunion in elective foot and ankle surgery and found that the nonunion rate in patients with vitamin D deficiency was eight times greater than in those without deficiency (level of evidence: III). Conversely, despite noting a significant prevalence of vitamin D deficiency, Michelson and Charlson[31] report that the level of vitamin D did not affect their outcome and union rates in elective foot and ankle surgery.

In a retrospective study of 98 patients, Warner et al[67] demonstrated that ankle fracture outcomes after operative fixation (measured at 1-year follow-up) were inferior in patients with low vitamin D levels (<50 nmol/L) perioperatively (level of evidence: IV).

Other Foot and Ankle Pathology. Calcaneal stiffness has been found to be greater with higher vitamin D concentrations in adolescents (level of evidence: IV).[68] This study, however, did not stratify for activity, which is an important confounding variable because calcaneal stiffness is also a sensitive marker of physical activity.[69] This may be due to repetitive loading rather than levels of vitamin D.

There are other purported associations between vitamin D and various foot and ankle pathologies, such as heel pain, Sever disease (calcaneal apophysitis), and other conditions. However, to our knowledge there is no conclusive evidence to suggest a link with any other foot and ankle conditions.

Bone Marrow Edema Syndrome. Bone marrow edema syndrome (BMES) is a condition that is not fully understood. The main features are a sudden onset of pain in the lower extremity and a hyperintense but ill-defined osseous signal on magnetic resonance imaging. The cause is unknown but involves increased bone turnover. Horas et al[70] conducted a retrospective study over 4 years and found that 84% of patients with BMES (26 of 31) had vitamin D deficiency (defined as <75 nmol/L) (level of evidence: IV). However, there was no comparator group to determine whether the rate of vitamin D deficiency was any different than in the general population. A smaller study of patients with BMES of the foot and ankle similarly found a high prevalence of vitamin D insufficiency (<75 nmol/L), osteoporosis, and osteopenia (level of evidence: IV).[71] They recommend that patients with BMES be referred for investigation and treatment of bone mineral density; however, no causality could be drawn between symptoms and vitamin D level, and it remains unclear whether vitamin D supplementation has any benefit in BMES.

Supplementation of Vitamin D

Diet is an important source of vitamin D, and it is accepted that a balanced diet should include foods naturally rich in, or fortified with, vitamin D.[15] Vitamin D intake can be in the form of either D_2 or D_3 measured in either international units or micrograms (1 IU = 0.025 μg, 1 μg = 40 IU). The recommended Reference Nutrient Intake for the UK population is 400 IU per day.[26] The Global Consensus Recommendations on Prevention and Management of Nutritional Rickets recommends 600 IU per day of vitamin D for children older than 1 year and adults and at least 500 mg per day of calcium.[14] In the United States the NIH suggests a recommended dietary allowance of 600 IU per day for all ages from 1 to 70 years (including pregnant and lactating women) and 800 IU per day for those older than 70 years.[72] These quantities are often not achieved through diet alone, and the NIH in the United States and the National Health Service in the United Kingdom recommend daily supplementation of 400 IU of vitamin D for at-risk groups.[72,73]

If adherence is good, daily supplementation of vitamin D has been demonstrated to be more effective than a large single dose.[74] Vitamin D toxicity is rare but can be seen at levels greater than 250 nmol/L, when it is often associated with hypercalciuria and low parathyroid hormone levels. Doses of up to 4,000 IU per day have been demonstrated as safe, and one study suggested that toxicity may not occur unless daily doses approach 40,000 IU.[12,14,24,75]

There is as yet no firm consensus on the specific quantity of supplementation required to prevent bone disease. It is, however, agreed that vitamin D should be co-supplemented with calcium. National UK guidelines for prevention of osteoporosis recommend vitamin D and calcium supplementation in all patients with osteoporosis and osteoporotic fractures.[16,76,77] Holick[13] examined prevention of fractures and falls with higher doses of vitamin D (up to 800 IU per day) and found that it was effective only when accompanied by calcium supplementation (level of evidence: III). Bischoff-Ferrari et al[37] performed a meta-analysis that suggested that 800 IU per day of both vitamin D and calcium was required to reduce fracture risk in the elderly (level of evidence: II).

Discussion

There are a few key limitations to effectively understanding the relevance of the literature on vitamin D to foot and ankle surgery. First, it is difficult to separate out the role of vitamin D from that of calcium because they are often co-administered in studies. Second, the literature on vitamin D is quite limited. Most of the research focuses on osteomalacia/rickets, and increasingly on fracture risk, stress fractures, muscle strength, and falls. Third, there is no consensus on the cutoff values used for vitamin D. The current global consensus is that 50 nmol/L is sufficient, but many studies use 75 nmol/L as a cutoff value. Because studies use different cutoff values, it is difficult to make meaningful comparisons between them. Furthermore, not all studies have provided data that can be extrapolated.

A further difficulty with applying the findings of studies involving vitamin D insufficiency to different population subgroups is the general prevalence of deficiency in the population and the seasonal and latitudinal variations in UVR. At latitude 52°N UVR is ineffective for synthesizing vitamin D in human skin from October through March, whereas at latitude 34°N vitamin D can be synthesized in the middle of winter.[78] Studies are often performed at higher latitudes, where vitamin D deficiency is more prevalent in the general population; it is, therefore, harder to attribute deficiency to the conditions being investigated.

Most of the literature consists of level III and IV evidence, and although their conclusions certainly merit further investigation with well-designed studies, it is easy to misattribute the cause of poorer outcomes when synthesizing conclusions from retrospective studies. Nevertheless, based on the combined results of the studies mentioned previously herein, several authors have recommended supplementation. Although they acknowledge that the evidence for its use is not strong, supplementation is cheap and safe.[79] In the United Kingdom the annual cost of vitamin D supplementation has been estimated to be £5.80 to £20.70, depending on the demographics and the dose required.[80] The costs in the United States are similar: at the time of writing this manuscript, 400 IU of vitamin D cost $0.06 per dose at major pharmacies, which equates to approximately $22.00 annually. Testing for vitamin D deficiency, in contrast, is relatively expensive. The costs vary widely according to provider and country but have been estimated to be approximately $50 per test in the United States[81] and £17 per test in the United Kingdom.[80] Considering the costs, the widespread prevalence of vitamin D deficiency, and the safety of low-dose supplementation, it seems unjustified to recommend routine testing in most patients.

A panel of experts convened by the American College of Foot and Ankle Surgeons, as part of a consensus group on perioperative management, could not reach a conclusion on whether vitamin D levels should be routinely tested before foot and ankle arthrodesis procedures for the aforementioned reasons (level of evidence: V).[82] In a consensus meeting of UK foot and ankle surgeons on the role of vitamin D and calcium in fractures, it was concluded that supplementation may reduce fracture risk and improve healing in high-risk or deficient groups, and they recommended that testing or direct supplementation might be appropriate in these patients (level of evidence: V).[83] The effects of routine supplementation in foot and ankle surgery, however, is yet to be determined, and most physicians do not routinely advise supplementation.[83]

Conclusions

More research is needed into the effect of vitamin D in foot and ankle surgery, including cost-benefit analysis of routine testing of vitamin D for foot and ankle pathologies. The best evidence available is for the role of vitamin D in preventing foot and ankle fractures (level II evidence available). The role of vitamin D in fracture healing, BMES, osteochondral lesions of the talus, strength around the foot and ankle, and tendon injures, however, is less clear (no level II evidence available). The evidence for vitamin D supplementation in foot and ankle surgery is not conclusive.

Based on this review of the literature, we cannot currently recommend routine testing or supplementation of vitamin D levels for patients with foot and ankle injury or those undergoing elective surgery. However, supplementation is cheap and safe and may be considered in high-risk groups. Better evidence in the form of high-quality studies is required for all aspects of vitamin D in the foot and ankle.

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