**An Insight Into The Impact of Vitamin D on Cardiovascular Outcomes in CKD**

Authors: Joey Junarta1,2, Vivekanand Jha3,4, Debasish Banerjee1,2

Institutions: 1Renal and Transplantation Unit, St George’s University Hospital NHS Foundation Trust; 2Cardiology Clinical Academic Group, Molecular and Clinical Sciences Research Institute, St George’s University of London; 3The George Institute of Global Health; 4University of Oxford.

Running title: Vitamin D in CKD

Word count: 3441

Tables: 4

Conflict of interest: None

Corresponding Address

Debasish Banerjee MD FRCP FHEA FASN

St Georges Hospital

Grosvenor Wing G2.113

Blackshaw Road, Tooting, London, SW17 0QT, UK

Telephone +44 2087251673

Fax +44 2087252068

Email [debasish.banerjee@stgeorges.nhs.uk](mailto:debasish.banerjee@stgeorges.nhs.uk)

Abstract

Patients with chronic kidney disease (CKD) experience excess cardiovascular morbidity and mortality that is unexplained by traditional cardiovascular risk factors. Vitamin D deficiency is highly prevalent in CKD and is associated with increased cardiovascular mortality in both the general population and in CKD patients. Vitamin D supplementation is a reasonably safe and simple intervention and meta-analyses of observational studies have suggested that vitamin D supplementation in CKD improves cardiovascular mortality. However, randomised controlled trials (RCTs) examining the impact of vitamin D supplementation in improving surrogate markers of cardiovascular structure and function remain inconclusive. This review investigates the impact of vitamin D supplementation on surrogate end-points and cardiovascular events from trials in CKD; and discusses why results have been heterogenous, particularly critiquing the effect of different dosing regimens and the failure to take into account the implications of vitamin D supplementation in study participants with differing vitamin D binding protein genotypes.

Key words: chronic kidney disease, cardiovascular disease, vitamin D, endothelial function, flow-mediated dilatation

Main text

*Introduction*

Patients with chronic kidney disease (CKD) experience excess cardiovascular morbidity and mortality, usually secondary to coronary heart disease and heart failure.1, 2 Traditional cardiovascular risk factors often present in CKD are unable to explain this excess risk, hence the interest in non-traditional risk factors such as vitamin D deficiency.

Vitamin D has a number of extra-skeletal physiological roles, including immunomodulation and cardiovascular protection.3 Associations between hypovitaminosis D and increased cardiovascular mortality has been demonstrated in both the general population and in CKD.4 Nutritional sources of vitamin D, cholecalciferol (D3) and ergocalciferol (D2), undergo two hydroxylation steps.3 The first occurs in the liver, forming 25-hydroxy vitamin D (25[OH]D), whilst the second occurs in the kidneys via the enzyme 1-α hydroxylase, forming active hormonal 1,25-dihydroxy vitamin D (1,25[OH]2D).3 Vitamin D deficiency is highly prevalent in CKD and there are several reasons for this.5 As CKD progresses, increased functional loss of renal tissue decreases the availability and functionality of 1-α hydroxylase, thereby decreasing 1,25(OH)2D levels.6 Additionally, CKD patients receive less nutritional vitamin D, since they often undergo intensive dietary restriction and lack sun exposure due to reduced mobility.6

As cardiovascular mortality is the commonest, often premature cause of mortality among those with CKD, the nephrology community has long sought for interventions that could improve the cardiovascular death in these patients. Vitamin D supplementation is reasonably safe and a simple intervention that could potentially help in this regard. Indeed, the meta-analysis by Duranton et al. demonstrated that active vitamin D supplementation in CKD reduced the relative risk of cardiovascular mortality by 37%.4 However, the studies reviewed therein were of observational design. In recent years, the impact of vitamin D on cardiovascular outcomes have been extensively investigated through randomised controlled trials (RCTs). Unfortunately, the results have been contradictory. This review investigates the impact of vitamin D on surrogate endpoints and hard cardiovascular outcomes in CKD. It also discusses why the results of these trials have been heterogeneous, particularly critiquing the effect of different dosing regimens and individual human biology.

*Abnormal Cardiovascular Structure and Function in Chronic Kidney Disease Patients*

Given the excess cardiovascular morbidity and mortality CKD patients experience, it is not surprising that they demonstrate abnormal cardiovascular structure and function. About 75% of non-dialysis CKD patients display left ventricular hypertrophy (LVH), making it one of the most prominent cardiovascular abnormality in CKD.8 The progression of LVH and change in systolic as well as diastolic functions have been shown to be closely related to the severity of kidney dysfunction.8

Endothelial dysfunction, arterial stiffness, and accelerated atherosclerosis are common in CKD.7 Traditional and non-traditional risk factors promote the development of endothelial dysfunction, which eventually leads to the development of atheromas. Intimal and medial calcification contribute to vascular stiffness, especially in association with progressive atherosclerotic lesions.

Flow-mediated dilation (FMD), an indicator of endothelial function that measures endothelial-dependent vasodilation, predicts CVD events in CKD.9 Nitroglycerin-mediated dilation (NMD) assesses endothelial-independent vasodilation which reflects vascular smooth muscle cell (SMC) function in response to an exogenous nitric oxide (NO) source. Pulse wave velocity (PWV) and aortic augmentation index (AIx) evaluate arterial stiffness. PWV is an independent predictor of CVD and mortality.9 Left atrial volume indexed to body surface area (LAVi) is a sensitive indicator of diastolic dysfunction.10 Patients with increased LAVi have a higher risk for CVD events.10 Left ventricular mass index (LVMI) and ejection fraction (EF) are also important markers. The impact of vitamin D on surrogate markers of these abnormalities in CKD have been investigated in both observational and interventional studies, including randomised controlled trials.

*Vitamin D Supplementation and Endothelial Dysfunction*

Table 1 summarises findings from RCTs investigating the impact of vitamin D supplementation on cardiovascular structure and function. The effect of vitamin D on improving endothelial dysfunction remains contradictory. Kumar et al. provides strong evidence that the correction of vitamin D deficiency improves FMD in pre-dialysis CKD patients.9 These findings agree with results from the PENNY trial, where 12-week paricalcitol supplementation improved FMD in CKD stage 3-4.11 However, unlike the study by Kumar and colleagues, improvements in NMD did not occur in the PENNY trial. Kumar et al. only recruited those with true vitamin D deficiency, which could explain the most impressive effects seen. In contrast, Thethi et al. did not demonstrate any improvements in both FMD and NMD with paricalcitol supplementation.12 However, this trial recruited diabetic CKD patients only, whereas there was a limited number of diabetics in the PENNY trial and Kumar’s group excluded diabetics entirely. The study by Kendrick and colleagues was also negative but they found no difference in the response of vitamin D on FMD by diabetes status.13 Considering this, it is unclear if the effect of vitamin D supplementation varies by diabetes status. The authors discussed that their negative findings may be due to insufficient doses of D3 and calcitriol, as optimal doses for CKD patients are unknown.13

*Vitamin D Supplementation and Vascular Stiffness*

Kumar’s group also demonstrated that D3 therapy improves PWV (Table 1).9 This is concordant with the study by Levin et al., where calcifediol supplementation improved PWV.14 However, PWV remain unchanged in the group receiving calcitriol in the latter study. Generally, those who achieved the highest serum levels of vitamin D following supplementation had the greatest improvement in PWV. Mose et al. investigated the impact of D3 supplementation on cardiac function in dialysis patients.15 However, their study was only powered to detect a difference in plasma brain natriuretic peptide (BNP) levels. The authors could not exclude that a larger sample size could reveal differences in other measures assessed, including PWV, AIx, LVMI, and EF. Similarly, Marckmann et al. did not demonstrate improvements in PWV or AIx with D3 administration.5 They too discussed that their study population was small and that their short intervention period of 8 weeks may not be enough to show improvements in the markers measured.5

*Vitamin D Supplementation and Cardiac Structure and Function*

The PRIMO (Paricalcitol Capsule Benefits in Renal Failure–Induced Cardiac Morbidity) trial demonstrated that paricalcitol supplementation over 48 weeks improved LAVi (Table 1).10 Decreases in LAVi was accompanied by attenuation in the rise in BNP. However, LVMI, EF, and Doppler measurements of diastolic function did not significantly change. The discrepancy between LAVi and Doppler measurements in evaluating diastolic function can be explained by the small sample size, which may not be enough to account for the known variability of Doppler measurements.10 Interestingly, a synergistic effect between paricalcitol and renin-angiotensin-aldosterone-system (RAAS) inhibition in decreasing LAVi was found. The largest decline in LAVi occurred in patients receiving both paricalcitol and RAAS inhibitors.10 In contrast, the study by Thadhani et al. failed to demonstrate improvements in LVMI, EF, or echocardiographic measures of diastolic function with paricalcitol therapy. However, paricalcitol attenuated the rise in BNP and reduced CVD hospitalisations.10 Wang et al. also found a lower incidence of cardiovascular-related hospitalisations with paricalcitol supplementation.16 Nonetheless, they too did not demonstrate improvements in LVMI, EF, or diastolic function with paricalcitol.

*Dose of Vitamin D and Hypercalcaemia in Randomised Controlled Trials*

The results of the randomised trials discussed above have been contradictory and inconclusive. This may be due to the heterogeneity in patient populations and dosing regimens. Doses have been kept low in studies, presumably to avoid hypercalcaemia, which was uncommon in all studies. Due to this, vitamin D levels did not rise to biologically significant levels. Additionally, some of the studies were of short duration. These factors may explain the lack of improvement in surrogate markers seen in certain studies.

The studies by Kumar et al.,9 Kendrick et al.,13 and Marckmann et al.,5 all used D3 as one of their study interventions in investigating the effect of vitamin D on endothelial dysfunction and/or vascular stiffness (Table 1). The total dose of D3 over the study period used by Kumar and colleagues was the highest amongst the three (600,000 IU), with 25(OH)D levels increasing by 24.91 ng/ml. This study was the only one that demonstrated improvements in all parameters measured. Importantly, no patient developed severe hypercalcaemia. Contrast this with the studies by Kendrick et al. and Marckmann et al., who administered less total dose of D3 over the study duration, at 420,000 IU and 320,000 IU, respectively. They showed no change in the surrogate markers investigated. Notably, only 1 of 58 patients in Kendrick’s D3 group developed hypercalcaemia.13 5 of 25 patients in Marckmann’s intervention group developed hypercalcaemia, but only 1 case was severe.5 The intervention group in their study achieved the highest levels of 25(OH)D at a median of 62 ng/ml, but there was no improvement in vascular stiffness.5 Their intervention lasted only 8 weeks, and it is possible that prolonged therapy with vitamin D could have improved certain markers.

Paricalcitol therapy was utilised in the studies by Zoccali et al. and Thethi et al. (Table 1).11, 12 With a dose of 2 mcg/day used by Zoccali’s group, improvements in endothelial function was demonstrated. Thethi’s group used a dose of 1 mcg/day, and failed to find a change. The incidence of hypercalcaemia was not discussed in their study, but only 2 of 44 patients in Zoccali’s intervention group developed frank hypercalcaemia (>2.75 mmol/L).

Paricalcitol was also used by Tamez et al.,10 Thadhani et al.,17 and Wang et al.,16 but here it was to assess its effects on cardiac structure and function. Using a dose of 2 mcg/day, Tamez’ study (post-hoc analysis of PRIMO trial) demonstrated improvements in LAVi, but not in other markers measured. However, LAVi is of more prognostic value compared to left ventricular morphology and function in patients with CKD.10 Thadhani and colleagues utilised the same dose over the same study duration, but improvements in cardiac structure and function were not shown. This is akin to the results reported by Wang’s group, who only used a dose of 1 mcg/day. The incidence of hypercalcaemia (serum calcium >2.62 mmol/L). in the study by Thadhani et al. was 22.6% It was 43.4% in the study by Wang’s group (>2.55 mmol/L). The majority of participants in Wang’s study were taking calcium-based phosphate binders. Upon stopping the binders, hypercalcaemia resolved without needing to adjust the paricalcitol dose.16

The importance of greater doses was evident in the trials evaluating endothelial dysfunction and vascular stiffness. This is less clear with the trials assessing cardiac structure and function, but Tamez and colleagues showed that a dose of at least 2 mcg/day of paricalcitol was needed to elicit any sort of improvement. Longer study durations may be needed to demonstrate improvements, as reductions in LAVi was further augmented between the 24th and 48th week in the study by Tamez’ group.10 It is important to stress that frank hypercalcaemia was uncommon in most studies. Considering this, increasing the doses and prolonging therapy may be important in uncovering improvements in surrogate markers assessed.

Another consideration to be made is the effect of different vitamin D formulations used on circulating 25(OH)D levels. 25(OH)D is the only vitamin D metabolite used to determine vitamin D sufficiency. 1,25(OH)2D is not an ideal measure for vitamin D status as the circulating half life of it is only 4-6 hours (compared to 2-3 weeks for 25[OH]D) and its circulating levels are a thousand fold less than 25(OH)D (c). Furthermore, vitamin D deficiency leads to decreased intestinal calcium absorption, causing increased production and secretion of parathyroid hormone (PTH) (c). This subsequently increases the renal production of 1,25(OH)2D. Hence, those with vitamin D insufficiency and deficiency have normal or elevated 1,25(OH)2D, making it a useless measure of vitamin D status (c). However, different vitamin D formulations have variable effects on circulating 25(OH)D. For example, 25(OH)D levels increased greatly with calcifediol supplementation in the study by Levin et al., but as expected decreased with calcitriol supplementation (Table 1). Thus, different formulations limit the ability to evaluate improvements in overall vitamin D status when it is defined by the level of circulating 25(OH)D.

*Vitamin D Supplementation and Cardiovascular Events and Mortality*

Meta-analyses of observational studies have shown an association between vitamin D supplementation and improvement in all-cause mortality, cardiovascular mortality, and all clinically significant end-points.4, 18 However, existing RCTs do not provide the same reassurance that vitamin D supplementation improves these hard end-points (Tables 2-4).5, 16, 17, 19-32 There seems to be no difference in the occurrence of events when comparing those treated with vitamin D derivatives and controls. Nevertheless, it is important to realise that these studies were not designed to assess the impact of vitamin D therapy on hard-end points. Only one of the RCTs listed mortality as an a priori primary or secondary outcome.20 Furthermore, the intervention duration and dosing regimens in individual trials differed substantially. As with the RCTs evaluating the impact of vitamin D supplementation on surrogate end-points, doses and the duration of treatment in certain studies may not have been enough to demonstrate differences. Thus, existing RCTs remain inconclusive about the effect of vitamin D supplementation on mortality and adverse cardiovascular outcomes in patients with CKD. This agrees with the meta-analysis of RCTs by Mann et al., who found no significant treatment effect of oral vitamin D on these end-points (b). However, they too cited that the heterogeneity between trials did not allow for appropriate evaluation of the impact of vitamin D therapy on cardiovascular risk and mortality (b).

The SIMPLIFIED trial (ISRCTN15087616) is the only ongoing RCT evaluating the impact of vitamin D supplementation on hard end-points. Study participants are randomised either to D3 therapy with a dose of 60,000 IU to be taken fortnightly or to receive normal standard care for five and a half years. The primary outcome measure is all-cause mortality which will be determined from seven years after the start of the study. The secondary outcomes of the study include hospitalisation-requiring composite cardiovascular events. This study is only recruiting adults with dialysis-requiring end stage renal disease.

More large-sized RCTs like the SIMPLIFIED trial that specify hard end-points as the primary or secondary outcome are needed to assess any potential benefit with vitamin D supplementation. Additionally, it is important that doses are high enough and the intervention lasts long enough before any conclusion can be drawn on the impact of supplementation on outcomes.

*Vitamin D and Human Biology*

Vitamin D mediates its effects on target cells by binding to the vitamin D receptor (VDR).5, 33 Vitamin D is bound to the VDR, which forms a liganded complex with the retinoid X receptor (RXR) after internalization.33 This complex then binds to vitamin D responsive elements in the promoter regions of vitamin D target genes, enabling the recruitment of transcriptional co-activators.33 Important co-activators include p160 and steroid receptor activators (SRC-1, SRC-2, SRC-3). Together, they lead to changes in gene expression.33 Genes regulated by vitamin D include but are not limited to RANKL, LRP5, CYP24A1, TRPV6, ENNP1, ENNP3, PDLIM2, GLUL, and SLC1A1.33 VDR expression is almost ubiquitous. It is found in the endothelium, vascular SMCs, and cardiomyocytes.10, 34 These cells can also locally convert circulating 25(OH)D to 1,25(OH)2D, as they carry local 1-α hydroxylase, and hence making active vitamin D available for local action when CKD patients are supplemented with 25(OH)D.34 1,25(OH)D is about 1000 times more potent in binding and mediating the local actions requiring far lower concentrations for VDR activation.3

Balanced production of endothelium-derived relaxing and contracting factors (EDRF and EDCF) ensures normal endothelial function. Imbalances in the production of these factors is associated with endothelial dysfunction.33 Vitamin D increases endothelial NO synthase expression, which is a synthesising enzyme of the EDRF NO.9, 33 In addition to maintaining endothelial function, an equally critical role of NO is to regulate LV (left ventricular) diastolic function.11 The coronary artery endothelium releases NO, which accelerates LV relaxation and increases LV distensibility.11 Thus, VDR activation is also important in increasing left ventricular (LV) lusitropy, hence critical for LV diastolic function.11

The RAAS is important in controlling vascular tone and volume homeostasis. Elevated activity in the setting of CVD is initially protective, as it allows the maintenance of cardiac output. However, it eventually leads to hypertension and cardiac hypertrophy, causing cardiac insufficiency. Vitamin D directly blocks renin expression by inhibiting the activity of the cyclic AMP response element in the renin gene promoter, thus suppressing the RAAS.35 Furthermore, mice with cardiomyocyte-selective deletion of VDR develop cardiac hypertrophy independent of changes in the RAAS, suggesting that it may have a direct anti-hypertrophic effect on the heart.36

Vitamin D may also be important to maintain the extracellular matrix integrity of the heart. Increased matrix metalloproteinase (MMP)-2 and MMP-9 and decreased tissue inhibitor of metalloproteinase (TIMP)-1 and TIMP-2 activity has been demonstrated in VDR knockout mice.37 This contributes to both systolic and diastolic dysfunction, as it is associated with increased fibrotic lesions.10, 37

It is important to discuss that the effect of vitamin D on vascular stiffness and structure may be non-linear, thus it can be both detrimental and protective to the vasculature. The anti-inflammatory effects of vitamin D is protective against atherosclerosis: it inhibits the release of inflammatory cytokines and blocks foam cell formation (a). However, vitamin D also induces vascular SMC osteogenic differentiation, which promotes MMP production leading to vascular remodeling (a). High doses of vitamin D may promote calcification, though the development of atherosclerosis and vascular stiffness also occurs in the setting of deficiency.

The vitamin D binding protein (DBP) functions as the primary carrier protein for all vitamin D metabolites in serum, binding 85-90% of total circulating 25(OH)D.38 The non-DBP fraction, also referred to as bioavailable 25(OH)D, consists mainly of albumin-bound 25(OH)D and free 25(OH)D.39 They make up 10-15% and less than 1% of total 25(OH)D, respectively.39

Studies have shown that DBP is highly polymorphic. Three phenotypic variants (*Gc1f, Gc1s, Gc2*) are commonly recognised and affect protein function, which has implications on vitamin D metabolism.39 These variants are determined by two single-nucleotide polymorphisms (SNPs) in the coding region of the DBP gene (rs4588 and rs7041).39 They determine serum DBP concentrations and cause changes in the amino acid sequence of DBP and appear to alter the binding affinity for vitamin D ligands.

The *Gc1f* phenotype has the highest affinity for vitamin D metabolites and *Gc2* the lowest.40, 41 In the HANDLS study, *Gc1f* homozygous participants had the lowest DBP levels whilst *Gc1s* homozygous participants had the highest. *Gc2* homozygous had intermediate levels of DBP.39 The prevalence of these polymorphisms differ between racial groups.33, 39 The *Gc1f* form of DBP is much more common amongst Black and Asian populations, while Whites are more likely to carry the *Gc1s* form of DBP. The *Gc2* form is rare in Blacks but more frequent in people of Asian and European ancestry.

In the HANDLS study, racial differences in total 25(OH)D levels were apparent, with levels of 17.3 ± 0.3 ng/ml in Blacks vs. 25.5 ± 0.4 ng/ml in whites after multivariable adjustment. DBP levels were also lower; 168 ± 3 mcg/ml in Blacks and 337 ± 5 mcg/ml in Whites. However, levels of bioavailable 25(OH)D were equivalent in Blacks and Whites. Vitamin D sufficiency has been determined at the level where total 25(OH)D causes calcium absorption to decline or PTH levels to increase.42, 43 The exact level of total 25(OH)D where these changes occur is controversial, as experimental data are inconclusive.20, 21 77-96% of Black participants in the HANDLS study would be classified as vitamin D deficient if current guidelines are used (threshold for sufficiency of 20 or 30 ng/ml).39 However, identifying them as vitamin D deficient would conflict with the observations of higher bone-mineral density, higher calcium levels, and only slightly higher PTH levels compared to the White study participants. Although levels of total 25(OH)D are low in Blacks, their low levels of DBP seems to be protective against the manifestations of vitamin D deficiency.39 The bio-availability of other lipophilic hormones are influenced by the concentration of their carrier proteins. For example, lower total thyroid hormone levels are required for sufficiency when the concentration of thyroxine-binding globulin is low or undetectable.44 Indeed, mice without DBP have low levels of 25(OH)D but do not demonstrate signs of vitamin D deficiency.45 Considering these findings altogether, low total 25(OH)D may not indicate true vitamin D deficiency when DBP levels are low. Thus, bioavailable 25(OH)D may be a more appropriate marker for vitamin D sufficiency. Importantly, in the HANDLS study, genetic variants independently explained 79.4% of the variation in DBP levels after adjustment for other factors.39 After genetic variants were accounted for, race explained <0.1% of the variation in DBP levels.39

The effect of vitamin D supplementation on total and bioavailable 25(OH)D levels in persons with different DBP genotypes is unclear. Studies evaluating the utility of vitamin D supplementation on soft and hard cardiovascular end-points in CKD patients have not taken this into account. Studies have hypothesized that correcting vitamin D deficiency would improve cardiovascular outcomes. However, sufficiency has been determined using 25(OH)D levels. Participants who have been recruited with low 25(OH)D levels may not have been truly vitamin D deficient when considering DBP levels. Hence, it is possible that further vitamin D supplementation would provide no further benefit in certain patients. Thus, may partly explain the lack of positive findings in RCTs. It would be useful for future RCTs to consider the implications of different DBP genotypes in recruited participants.

*Conclusion*

Meta-analyses of observational studies have suggested that vitamin D supplementation in CKD patients improves mortality, including cardiovascular mortality.4, 18 However, RCTs evaluating the utility of vitamin D supplementation in improving surrogate markers of cardiovascular structure and function remain inconclusive. In many cases, the interventional dose has been kept low in fear of developing hypercalcaemia, which is uncommon. Thus, vitamin D levels in study participants did not rise significantly, which may explain the negative findings. Furthermore, the use of different vitamin D formulations limit the ability to compare improvements in overall vitamin D status between studies. Meanwhile, there are no completed RCTs that are appropriately designed to evaluate the impact of vitamin D supplementation on hard end-points in CKD. The SIMPLIFIED trial is projected to finish in 2025 and will hopefully provide an improved understanding of the role of vitamin D supplementation in improving all-cause and cardiovascular mortality in CKD patients.

Currently, the implications of vitamin D supplementation in patients with differing DBP genotypes is unclear. Indeed, previous trials have not taken this into account. More research is needed to further clarify the role of DBP in enabling true vitamin D sufficiency. Also, further research to understand the mechanism by which vitamin D effects the cardiovascular system is needed.

With these considerations in mind, the nephrology community may be able to find the right dose for the right patient to improve cardiovascular morbidity and mortality in CKD the population.

Acknowledgements

VJ has funding from the Department of Biotechnology, Government of India. DB received funding from British Heart Foundation, St. George’s Charity and British Renal Society.

References

1. Astor BC, Coresh J, Heiss G, Pettitt D, Sarnak MJ: Kidney function and anemia as risk factors for coronary heart disease and mortality: The atherosclerosis risk in communities (ARIC) study. [Electronic version]. *Am Heart J* 151: 492-500, 2006

2. Kottgen A, Russell SD, Loehr LR, et al: Reduced kidney function as a risk factor for incident heart failure: The atherosclerosis risk in communities (ARIC) study. [Electronic version]. *J Am Soc Nephrol* 18: 1307-1315, 2007

3. Holick MF: Vitamin D deficiency. [Electronic version]. *N Engl J Med* 357: 266-281, 2007

4. Duranton F, Rodriguez-Ortiz ME, Duny Y, Rodriguez M, Daures JP, Argiles A: Vitamin D treatment and mortality in chronic kidney disease: A systematic review and meta-analysis. [Electronic version]. *Am J Nephrol* 37: 239-248, 2013

5. Marckmann P, Agerskov H, Thineshkumar S, et al: Randomized controlled trial of cholecalciferol supplementation in chronic kidney disease patients with hypovitaminosis D. [Electronic version]. *Nephrol Dial Transplant* 27: 3523-3531, 2012

6. Melamed ML, & Thadhani RI: Vitamin D therapy in chronic kidney disease and end stage renal disease. [Electronic version]. *Clin J Am Soc Nephrol* 7: 358-365, 2012

7. Zoccali C, Bode-Boger S, Mallamaci F, et al: Plasma concentration of asymmetrical dimethylarginine and mortality in patients with end-stage renal disease: A prospective study. [Electronic version]. *Lancet* 358: 2113-2117, 2001

8. Cai QZ, Lu XZ, Lu Y, Wang AY: Longitudinal changes of cardiac structure and function in CKD (CASCADE study). [Electronic version]. *J Am Soc Nephrol* 25: 1599-1608, 2014

9. Kumar V, Yadav AK, Lal A, et al: A randomized trial of vitamin D supplementation on vascular function in CKD. [Electronic version]. *J Am Soc Nephrol* 28: 3100-3108, 2017

10. Tamez H, Zoccali C, Packham D, et al: Vitamin D reduces left atrial volume in patients with left ventricular hypertrophy and chronic kidney disease. [Electronic version]. *Am Heart J* 164: 902-9.e2, 2012

11. Zoccali C, Curatola G, Panuccio V, et al: Paricalcitol and endothelial function in chronic kidney disease trial. [Electronic version]. *Hypertension* 64: 1005-1011, 2014

12. Thethi TK, Bajwa MA, Ghanim H, et al: Effect of paricalcitol on endothelial function and inflammation in type 2 diabetes and chronic kidney disease. [Electronic version]. *J Diabetes Complications* 29: 433-437, 2015

13. Kendrick J, Andrews E, You Z, et al: Cholecalciferol, calcitriol, and vascular function in CKD: A randomized, double-blind trial. [Electronic version]. *Clin J Am Soc Nephrol* 12: 1438-1446, 2017

14. Levin A, Tang M, Perry T, et al: Randomized controlled trial for the effect of vitamin D supplementation on vascular stiffness in CKD. [Electronic version]. *Clin J Am Soc Nephrol* 12: 1447-1460, 2017

15. Mose FH, Vase H, Larsen T, et al: Cardiovascular effects of cholecalciferol treatment in dialysis patients--a randomized controlled trial. [Electronic version]. *BMC Nephrol* 15: 50-2369-15-50, 2014

16. Wang AY, Fang F, Chan J, et al: Effect of paricalcitol on left ventricular mass and function in CKD--the OPERA trial. [Electronic version]. *J Am Soc Nephrol* 25: 175-186, 2014

17. Thadhani R, Appelbaum E, Pritchett Y, et al: Vitamin D therapy and cardiac structure and function in patients with chronic kidney disease: The PRIMO randomized controlled trial. [Electronic version]. *JAMA* 307: 674-684, 2012

18. Lu RJ, Zhu SM, Tang FL, et al: Effects of vitamin D or its analogues on the mortality of patients with chronic kidney disease: An updated systematic review and meta-analysis. [Electronic version]. *Eur J Clin Nutr* 71: 683-693, 2017

19. Alvarez JA, Law J, Coakley KE, et al: High-dose cholecalciferol reduces parathyroid hormone in patients with early chronic kidney disease: A pilot, randomized, double-blind, placebo-controlled trial. [Electronic version]. *Am J Clin Nutr* 96: 672-679, 2012

20. Bhan I, Dobens D, Tamez H, et al: Nutritional vitamin D supplementation in dialysis: A randomized trial. [Electronic version]. *Clin J Am Soc Nephrol* 10: 611-619, 2015

21. Coburn JW, Maung HM, Elangovan L, et al: Doxercalciferol safely suppresses PTH levels in patients with secondary hyperparathyroidism associated with chronic kidney disease stages 3 and 4. [Electronic version]. *Am J Kidney Dis* 43: 877-890, 2004

22. Coyne D, Acharya M, Qiu P, et al: Paricalcitol capsule for the treatment of secondary hyperparathyroidism in stages 3 and 4 CKD. [Electronic version]. *Am J Kidney Dis* 47: 263-276, 2006

23. de Zeeuw D, Agarwal R, Amdahl M, et al: Selective vitamin D receptor activation with paricalcitol for reduction of albuminuria in patients with type 2 diabetes (VITAL study): A randomised controlled trial. [Electronic version]. *Lancet* 376: 1543-1551, 2010

24. Delanaye P, Weekers L, Warling X, et al: Cholecalciferol in haemodialysis patients: A randomized, double-blind, proof-of-concept and safety study. [Electronic version]. *Nephrol Dial Transplant* 28: 1779-1786, 2013

25. Frazao JM, Elangovan L, Maung HM, et al: Intermittent doxercalciferol (1alpha-hydroxyvitamin D(2)) therapy for secondary hyperparathyroidism. [Electronic version]. *Am J Kidney Dis* 36: 550-561, 2000

26. Hamdy NA, Kanis JA, Beneton MN, et al: Effect of alfacalcidol on natural course of renal bone disease in mild to moderate renal failure. [Electronic version]. *Bmj* 310: 358-363, 1995

27. Hewitt NA, O'Connor AA, O'Shaughnessy DV, Elder GJ: Effects of cholecalciferol on functional, biochemical, vascular, and quality of life outcomes in hemodialysis patients. [Electronic version]. *Clin J Am Soc Nephrol* 8: 1143-1149, 2013

28. Li L, Lin M, Krassilnikova M, et al: Effect of cholecalciferol supplementation on inflammation and cellular alloimmunity in hemodialysis patients: Data from a randomized controlled pilot trial. [Electronic version]. *PLoS One* 9: e109998, 2014

29. Massart A, Debelle FD, Racape J, et al: Biochemical parameters after cholecalciferol repletion in hemodialysis: Results from the VitaDial randomized trial. [Electronic version]. *Am J Kidney Dis* 64: 696-705, 2014

30. Memmos DE, Eastwood JB, Talner LB, et al: Double-blind trial of oral 1,25-dihydroxy vitamin D3 versus placebo in asymptomatic hyperparathyroidism in patients receiving maintenance haemodialysis. [Electronic version]. *Br Med J (Clin Res Ed)* 282: 1919-1924, 1981

31. Merino JL, Teruel JL, Fernandez-Lucas M, et al: Effects of a single, high oral dose of 25-hydroxycholecalciferol on the mineral metabolism markers in hemodialysis patients. [Electronic version]. *Ther Apher Dial* 19: 212-219, 2015

32. Wasse H, Huang R, Long Q, Singapuri S, Raggi P, Tangpricha V: Efficacy and safety of a short course of very-high-dose cholecalciferol in hemodialysis. [Electronic version]. *Am J Clin Nutr* 95: 522-528, 2012

33. Christakos S, Dhawan P, Verstuyf A, Verlinden L, Carmeliet G: Vitamin D: Metabolism, molecular mechanism of action, and pleiotropic effects. [Electronic version]. *Physiol Rev* 96: 365-408, 2016

34. Luo Q, Wang LL, Gao YH: Association between serum 25-hydroxyvitamin D and arterial stiffness in non-dialysis-dependent CKD. [Electronic version]. *Eur J Clin Nutr* 70: 274-276, 2016

35. Yuan W, Pan W, Kong J, et al: 1,25-dihydroxyvitamin D3 suppresses renin gene transcription by blocking the activity of the cyclic AMP response element in the renin gene promoter. [Electronic version]. *J Biol Chem* 282: 29821-29830, 2007

36. Chen S, Law CS, Grigsby CL, et al: Cardiomyocyte-specific deletion of the vitamin D receptor gene results in cardiac hypertrophy. [Electronic version]. *Circulation* 124: 1838-1847, 2011

37. Rahman A, Hershey S, Ahmed S, Nibbelink K, Simpson RU: Heart extracellular matrix gene expression profile in the vitamin D receptor knockout mice. [Electronic version]. *J Steroid Biochem Mol Biol* 103: 416-419, 2007

38. Bikle DD, Gee E, Halloran B, Kowalski MA, Ryzen E, Haddad JG: Assessment of the free fraction of 25-hydroxyvitamin D in serum and its regulation by albumin and the vitamin D-binding protein. [Electronic version]. *J Clin Endocrinol Metab* 63: 954-959, 1986

39. Powe CE, Evans MK, Wenger J, et al: Vitamin D-binding protein and vitamin D status of black americans and white americans. [Electronic version]. *N Engl J Med* 369: 1991-2000, 2013

40. Arnaud J, & Constans J: Affinity differences for vitamin D metabolites associated with the genetic isoforms of the human serum carrier protein (DBP). [Electronic version]. *Hum Genet* 92: 183-188, 1993

41. Bouillon R, van Baelen H, de Moor P: Comparative study of the affinity of the serum vitamin D-binding protein. [Electronic version]. *J Steroid Biochem* 13: 1029-1034, 1980

42. Sai AJ, Walters RW, Fang X, Gallagher JC: Relationship between vitamin D, parathyroid hormone, and bone health. [Electronic version]. *J Clin Endocrinol Metab* 96: E436-46, 2011

43. Rosen CJ, Abrams SA, Aloia JF, et al: IOM committee members respond to endocrine society vitamin D guideline. [Electronic version]. *J Clin Endocrinol Metab* 97: 1146-1152, 2012

44. Mori Y, Takeda K, Charbonneau M, Refetoff S: Replacement of Leu227 by pro in thyroxine-binding globulin (TBG) is associated with complete TBG deficiency in three of eight families with this inherited defect. [Electronic version]. *J Clin Endocrinol Metab* 70: 804-809, 1990

45. Safadi FF, Thornton P, Magiera H, et al: Osteopathy and resistance to vitamin D toxicity in mice null for vitamin D binding protein. [Electronic version]. *J Clin Invest* 103: 239-251, 1999

Tables

Legend: *n* number of participants, *CKD* chronic kidney disease, *D3* cholecalciferol, *FMD* flow-mediated dilation, *NMD* nitroglycerin-mediated dilation, *PWV* pulse wave velocity, *LAVi* left atrial volume index

†(95% confidence interval)

‡median (interquartile range)

§Calcium levels of study is unreliable

**Table 1.** Summary of randomised controlled trials examining impact of vitamin D on cardiovascular structure and function

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Study | n | Population | Intervention | Duration | Changes in surrogate markers | Changes in 25(OH)D (ng/ml) and Calcium (mmol/L) |
| Kumar et al.9 | 120 | CKD 3-4 | D3 300,000 IU x 2 (at baseline and 8 weeks)  Placebo | 16 weeks | **Improvements in FMD, NMD, PWV** | **25(OH)D**: 13.40 ± 4.42 (baseline), changed by 24.91 (21.77-28.06)† by week 16  **Calcium**: 2.25 ± 0.18 to 2.30 (2.23-2.36)† |
| Zoccali et al.11 | 89 | CKD 3-4 | Paricalcitol 2 mcg/day  Placebo | 12 weeks | **Improvements in FMD**  **No changes in NMD** | **25(OH)D**: increased by 2 (0.4-3.6)  **Calcium**: increased by 0.07 (0.03-0.11) |
| Thethi et al.12 | 60 | CKD 3-4 (diabetic) | Paricalcitol 1 mcg/day  Placebo | 12 weeks | **No changes in FMD, NMD** | **1,25(OH)2D**: 45.0 (27.0–91.0)‡ pg/ml (baseline)  **Calcium**: not reported |
| Kendrick et al.13 | 128 | CKD | Calcitriol 0.25 mcg/day for month 1, increased to 0.5 mcg/day for months 2-6 if episodes of hypercalcaemia do not occur  D3 4000 IU/day for month 1, 2000 IU/day for months 2-6 | 6 months | **No changes in FMD, NMD** | **Calcitriol group 25(OH)D**: 21.7 ± 7.7 to 21.2 ± 7.5  **D3 group 25(OH)D**: 23.0 ± 7.6 to 34.8 ± 9.3  **Calcitriol group calcium**: 2.25 ± 0.1 to 2.27 ± 0.15  **D3 group calcium**: 2.27 ± 0.1 to 2.25 ± 0.1 |
| Levin et al.14 | 119 | CKD 3B-4 | Calcitriol (1,25[OH]2D) 0.5 mcg x 3/week  Calcifediol (25[OH]D) 5000 IU x 3/week  Placebo | 6 months | **Improvements in PWV** in calcifediol group | **Calcitriol group 25(OH)D**: 26.6 ± 10.8 to 23.8 ± 8.9  **Calcifediol group 25(OH)D**: 25.8 ± 9.6 to 94.1 ± 51.9  **Calcitriol group calcium**: 2.32 ± 0.12 to 2.35 ± 0.12  **Calcifediol group calcium**: 2.30 ± 0.12 to 2.32 ± 0.12 |
| Mose et al.15 | 64 | CKD (dialysis) | D3 3000 IU/day  Placebo | 6 months | **No changes in PWV, AIx, LVMI, EF** | **25(OH)D**: 11.2 (8-19.2)‡ to 33.6 (26-50)‡  **Calcium**§ |
| Marckmann et al.5 | 54 | CKD | D3 40,000 IU/week  Placebo | 8 weeks | **No changes in PWV, AIx** | **25(OH)D**: 9.6 (6.8–16.4)‡ to 62 (32.4–96)‡  **Calcium**: 2.27 (2.21–2.27)‡ (baseline), changed by 0.05 (-0.07-0.22)‡ by week 8 |
| Tamez et al.10 | 196 | CKD | Paricalcitol 2 mcg/day  Placebo | 48 weeks | **Improvements in LAVi**  **No changes in LVMI, EF** | **25(OH)D**: not reported  **Calcium**: 2.40 (2.30-2.45)‡ (baseline), changed by 0.07 (0.05-0.10)† by week 48 |
| Thadhani et al.17 | 227 | CKD | Paricalcitol 2 mcg/day  Placebo | 48 weeks | **No changes in LVMI, EF, diastolic function** | **25(OH)D**: not reported  **Calcium**: 2.40 (9.30-9.45)‡ (baseline), changed by 0.08 (0.05-0.11)† by week 48 |
| Wang et al.16 | 60 | CKD 3-5 (non-dialysis) | Paricalcitol 1 mcg/day  Placebo | 52 weeks | **No changes in LVMI, EF, diastolic function** | **25(OH)D**: not reported  **Calcium**: 2.32 ± 0.10 to 2.39 ± 0.11 |

Legend: *n* number of participants, *CKD* chronic kidney disease, *HD* haemodialysis, *D3* cholecalciferol, *D2* ergocalciferol, *PTH* parathyroid hormone, *RCT* randomised controlled trial

**Table 2.** Summary of randomised controlled trials examining impact of vitamin D supplementation on all cause mortality

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Study | Population | Intervention | Duration | n placebo | n treatment | Events in Placebo Group | Events in Treatment Group |
| Alvarez et al.19 | CKD 2-3 | D3 50,000 IU/week for 12 weeks followed by 50,000 IU every other week for 40 weeks | 52 weeks | 24 | 22 | 1 | 1 |
| Bhan et al.20 | CKD (HD) | D2 50,000 IU/week  D2 50,000 IU/month | 12 weeks | 36 | 36 (D2 weekly)  33 (D2 monthly) | 5 | 3 (D2 weekly) |
| Coburn et al.21 | CKD 3-4 | Doxercalciferol 1 mcg/day increased by 0.5 mcg/day every month depending on PTH levels with a maximum permitted dose of 5 mcg/day | 24 weeks | 28 | 27 | 1 | 0 |
| Coyne et al.22 | CKD 3-4 | Three RCTs were discussed in this study:  Study 1 & 2 dose:  Paricalcitol 2 mcg x 3/week or Paricalcitol 4 mcg x 3/week depending on PTH levels  Study 3 dose:  Paricalcitol 1 mcg/day  Doses in all 3 trials were adjusted accordingly throughout the trial duration depending on serum calcium, phosphorus, and PTH levels | 24 weeks | 113 | 107 | 1 | 2 |
| de Zeeuw et al.23 | CKD (diabetic) | Paricalcitol 1 mcg/day  Paricalcitol 2 mcg/day | 24 weeks | 93 | 93 (1 mcg/day)  95 (2 mcg/day) | 0 | 2 |
| Delanaye et al.24 | CKD (HD) | D3 25,000 IU every 2 weeks | 12 months | 21 | 22 | 5 | 6 |
| Frazao et al.25 | CKD (HD) | Doxercalciferol 10 mcg x 3/week | 8 weeks | 67 | 71 | 2 | 1 |
| Hamdy et al.26 | CKD | Alfacalcidol 0.25 mcg/day (titrated according to serum calcium concentration) | 2 years (or until patient required dialysis) | 87 | 89 | 1 | 4 |
| Hewitt et al.27 | CKD (HD) | D3 50,000 IU/week for 8 weeks, then 50,000 IU/month for 4 months | 6 months | 30 | 30 | 1 | 1 |
| Li et al.28 | CKD (HD) | D3 50,000 IU/week | 12 months | 34 | 62 | 2 | 10 |
| Marckmann et al.5 | CKD | D3 40,000 IU/week | 8 weeks | 27 | 27 | 1 | 0 |
| Massart et al.29 | CKD (HD) | D3 25,000 IU/week | 13 weeks | 29 | 26 | 1 | 0 |
| Memmos et al.30 | CKD (HD) | D3 0.25 mcg or 0.50 mcg | 1 or 2 years | 30 | 27 | 3 | 3 |
| Merino et al.31 | CKD (HD) | D3 180,000 IU x 1 | 16 weeks | 47 | 47 | 2 | 3 |
| Thadhani et al.17 | CKD | Paricalcitol 2 mcg/day | 48 weeks | 112 | 115 | 1 | 1 |
| Wasse et al.32 | CKD (HD) | D3 200,000 IU/week | 3 weeks | 27 | 25 | 1 | 2 |
| Wang et al.16 | CKD 3-5 (non-dialysis) | Paricalcitol 1 mcg/day | 52 weeks | 30 | 30 | 0 | 0 |

Legend: *n* number of participants, *CKD* chronic kidney disease, *HD* haemodialysis, *D3* cholecalciferol, *PTH* parathyroid hormone

**Table 3.** Summary of randomised controlled trials examining impact of vitamin D supplementation on cardiovascular mortality

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Study | Population | Intervention | Duration | n placebo | n treatment | Events in Placebo Group | Events in Treatment Group |
| Coburn et al.21 | CKD 3-4 | Doxercalciferol 1 mcg/day increased by 0.5 mcg/day every month depending on PTH levels with a maximum permitted dose of 5 mcg/day | 24 weeks | 28 | 27 | 1 | 0 |
| de Zeeuw et al.23 | CKD (diabetic) | Paricalcitol 1 mcg/day  Paricalcitol 2 mcg/day | 24 weeks | 93 | 93 (1 mcg/day)  95 (2 mcg/day) | 0 | 1 |
| Frazao et al.25 | CKD (HD) | Doxercalciferol 10 mcg x 3/week | 8 weeks | 67 | 71 | 2 | 1 |
| Hamdy et al.26 | CKD | Alfacalcidol 0.25 mcg/day (titrated according to serum calcium concentration) | 2 years (or until patient required dialysis) | 87 | 89 | 1 | 4 |
| Hewitt et al.27 | CKD (HD) | D3 50,000 IU/week for 8 weeks, then 50,000 IU/month for 4 months | 6 months | 30 | 30 | 0 | 1 |
| Massart et al.29 | CKD (HD) | D3 25,000 IU/week | 13 weeks | 29 | 26 | 1 | 0 |
| Merino et al.31 | CKD (HD) | D3 180,000 x 1 | 16 weeks | 47 | 47 | 0 | 1 |
| Thadhani et al.17 | CKD | Paricalcitol 2 mcg/day | 48 weeks | 112 | 115 | 1 | 1 |

Legend: *n* number of participants, *CKD* chronic kidney disease, *HD* haemodialysis, *D3* cholecalciferol, *D2* ergocalciferol, *PTH* parathyroid hormone, *RCT* randomised controlled trial

**Table 4.** Summary of randomised controlled trials examining impact of vitamin D supplementation on cardiovascular adverse events

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Study | Population | Intervention | Duration | n placebo | n treatment | Events in Placebo Group | Events in Treatment Group |
| Bhan et al.20 | CKD (HD) | D2 50,000 IU/week  D2 50,000 IU/month | 12 weeks | 36 | 36 (D2 weekly)  33 (D2 monthly) | 3 | 6 (D2 weekly)  2 (D2 monthly) |
| Coburn et al.21 | CKD 3-4 | Doxercalciferol 1 mcg/day increased by 0.5 mcg/day every month depending on PTH levels with a maximum permitted dose of 5 mcg/day | 24 weeks | 28 | 27 | 2 | 1 |
| Coyne et al.22 | CKD 3-4 | Three RCTs were discussed in this study:  Study 1 & 2 dose:  Paricalcitol 2 mcg x 3/week or Paricalcitol 4 mcg x 3/week depending on PTH levels  Study 3 dose:  Paricalcitol 1 mcg/day  Doses in all 3 trials were adjusted accordingly throughout the trial duration depending on serum calcium, phosphorus, and PTH levels | 24 weeks | 113 | 107 | 0 | 1 |
| de Zeeuw et al.23 | CKD (diabetic) | Paricalcitol 1 mcg/day  Paricalcitol 2 mcg/day | 24 weeks | 93 | 93 (1 mcg/day)  95 (2 mcg/day) | 1 | 5 |
| Frazao et al.25 | CKD (HD) | Doxercalciferol 10 mcg x 3/week | 8 weeks | 67 | 71 | 2 | 1 |
| Hamdy et al.26 | CKD | Alfacalcidol 0.25 mcg/day (titrated according to serum calcium concentration) | 2 years (or until patient required dialysis) | 87 | 89 | 2 | 1 |
| Hewitt et al.27 | CKD (HD) | D3 50,000 IU/week for 8 weeks, then 50,000 IU/month for 4 months | 6 months | 30 | 30 | 0 | 1 |
| Massart et al.29 | CKD (HD) | D3 25,000 IU/week | 13 weeks | 29 | 26 | 9 | 4 |
| Thadhani et al.17 | CKD | Paricalcitol 2 mcg/day | 48 weeks | 112 | 115 | 8 | 2 |
| Wang et al.16 | CKD 3-5 (non-dialysis) | Paricalcitol 1 mcg/day | 52 weeks | 30 | 30 | 3 | 0 |