Clinical Research Protocol

Clearance of 25-hydroxyvitamin D_3 during vitamin D_3 supplementation

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LIST OF ABBREVIATIONS

AE	adverse event
ALT	alanine aminotransferase
AST	aspartate aminotransferase
BUN	blood urea nitrogen
CFR	Code of Federal Regulations
CRF	case report form
FDA	Food and Drug Administration
GCP	Good Clinical Practice
HIPAA	Health Insurance Portability and Accountability Act of 1996
ICF	informed consent form
ICH	International Conference on Harmonisation
IEC	Independent Ethics Committee
IRB	Institutional Review Board
IV	intravenous
PI	Principal Investigator
PK	pharmacokinetic
SAE	serious adverse experience
SGOT	serum glutamic oxaloacetic transaminase
SGPT	serum glutamate pyruvate transaminase

PROTOCOL SYNOPSIS

TITLE	Clearance of 25-hydroxyvitamin D_3 during vitamin D_3 supplementation
SPONSOR	Ian H. de Boer, MD, MS
FUNDING ORGANIZATION	National Institute of Diabetes and Digestive and Kidney Diseases (R01DK099199)
NUMBER OF SITES	Single-site study
RATIONALE	Vitamin D clearance is an important and often overlooked aspect of vitamin D biology that has relevant implications for the clinical assessment and treatment of vitamin D deficiency. The circulating concentration of 25-hydroxyvitamin D [25(OH)D] is the most widely accepted measure of vitamin D status, and vitamin D supplements are often prescribed and titrated based on 25(OH)D concentration. However, circulating concentrations of 25(OH)D are necessarily determined by both 25(OH)D production and 25(OH)D clearance. Therefore, 25(OH)D clearance likely plays an important role in the assessment of vitamin D status and the response to vitamin D supplementation. The goal of this study is to determine how 25(OH)D_3 clearance is affected by vitamin D_3 supplementation using a gold standard pharmacokinetic approach. We expect that this study will enhance interpretation of available diagnostic tests, inform the results of ongoing large clinical trials of vitamin D supplements, and help develop new strategies to target vitamin D to improve health.
STUDY DESIGN	This is a single-dose, open-label pharmacokinetic study that uses intravenous administration of a stable deuterium-labeled 25(OH)D_3 to evaluate the metabolic clearance of 25(OH)D_3 in subjects that supplement their diet with vitamin D_3. These data will be compared with previously acquired "un-supplemented" measurements obtained from the same patients. This study will only enroll subjects who previously participated in the CLEAR or CLEAR-CF protocol and from whom un-supplemented measurements of 25(OH)D_3 clearance were obtained. The CLEAR and CLEAR-CF protocols are both included under IND 115016. In this study, a repeat measurement of 25(OH)D_3 clearance will be obtained from eligible subjects who are supplementing their diet with a stable dose of Vitamin D_3, defined as cholecalciferol 2000 IU daily. The patterns of 25(OH)D_3 clearance in these patients, with and without vitamin D_3 supplementation, will be assessed.

	Allocation: Non-Randomized **Intervention Model**: Single Group Assignment **Masking**: Open Label
PRIMARY OBJECTIVE	The goal of this study is to determine if 25(OH)D_3 clearance is affected by vitamin D_3 supplementation.
SECONDARY OBJECTIVES	• To explore whether disease status (chronic kidney disease or cystic fibrosis) modify the 25(OH)D_3 clearance response to vitamin D_3 supplementation. • To evaluate biomarkers of 25(OH)D_3 clearance during vitamin D_3 supplementation.
NUMBER OF SUBJECTS	Up to 20
SUBJECT SELECTION CRITERIA	Inclusion Criteria: • Successful completion of related protocol CLEAR or CLEAR-CF, defined as: o Previous administration of D_6-25-hydroxyvitamin D_3 Solution under the CLEAR or CLEAR-CF protocol, o Completion of at least 7 CLEAR or CLEAR-CF study visits, and o Absence of adverse events related to D_6-25-hydroxyvitamin D_3 Solution administration during participation in CLEAR or CLEAR-CF Exclusion Criteria: • Primary hyperparathyroidism • Gastric bypass • Tuberculosis or sarcoidosis • Current pregnancy • Child-Pugh Class B or C cirrhosis (i.e. cirrhosis with ascites, hepatic encephalopathy, bilirubin >=2 mg/dL, serum albumin <=3.5 g/dL, or PT >= 4 seconds) • History of kidney transplantation (unless failed transplant now treated with hemodialysis) • Use of 1,25$(OH)_2D_3$ or an analogue, calcimimetics, or medications known to induce CYP24A1 within 4 weeks (wash-out allowed) • Serum calcium > 10.1 mg/dL • Hemoglobin < 9 g/dL
TEST PRODUCT, DOSE, AND ROUTE OF ADMINISTRATION	We will administer D_6-25-hydroxyvitamin D_3 Solution for Injection, 20 µg/mL intravenously. The deuterated 25(OH)D_3 is formulated using cosolvents to enhance solubility. Each mL contains 20 µg D_6-25(OH) D3, 60% propylene glycol, 10% ethanol (ETOH) and water (30%) for injection, to volume. To

	ensure reliable detection of circulating deuterated 25(OH)D_3, without administering a dose that might alter the underlying vitamin D metabolism, we aim to administer a dose that results in a peak deuterated 25(OH)D_3 concentration of approximately 5 ng/mL. The administered dose will be calculated as the targeted peak serum deuterated 25(OH)D_3 (5 ng/mL) multiplied by blood volume.
CONTROL PRODUCT, DOSE AND ROUTE OF ADMINISTRATION	There is no control product.
DURATION OF SUBJECT PARTICIPATION AND DURATION OF STUDY	Subjects will be on study for approximately 6 months **Screening and vitamin D_3 supplement run-in:** 3 months **Re-screening and scheduling:** approximately 1 month **Treatment:** 1 day (subjects to the University of Washington Clinical Research Center) **Follow-up:** 8 weeks The total duration of the study is expected to be up to 18 months for subject recruitment and an additional 12 weeks for final subject follow-up.
CONCOMMITANT MEDICATIONS	**Required:** • Vitamin D_3 (cholecalciferol) 2000 IU daily by mouth from start of run-in through completion of follow-up, provided by study team **Allowed:** • Additional vitamin D supplements (cholecalciferol or ergocalciferol, alone or contained in multivitamins) not to exceed a mean daily dose of 400 IU **Prohibited** (from 4 weeks prior to D_6-25-hydroxyvitamin D_3 until completion of the study): • 1,25$(OH)_2D_3$ or an analogue (e.g. paricalcitol, hectorol) • Calcimimetics (e.g. cinaclacet) • Medications known to potently induce or inhibit CYP24A1 or CYP3A4
EFFICACY EVALUATIONS	None
PRIMARY ENDPOINT	• Metabolic clearance of labeled 25(OH)D_3 (administered dose/AUC)
SECONDARY ENDPOINTS	• AUC of labeled 25(OH)D_3 • Terminal half-life of labeled 25(OH)D_3

	• Volume of distribution in the central compartment of labeled $25(OH)D_3$
OTHER EVALUATIONS	Metabolic formation clearance (metabolite/parent AUC ratio) for metabolites of labeled $25(OH)D_3$
SAFETY EVALUATIONS	Change in the serum concentrations of calcium, creatinine, AST, and ALT and from baseline to 7 days after $25(OH)D_3$ administration Incidence of adverse events
PLANNED INTERIM ANALYSES	This is not a clinical trial with an efficacy outcome, and it is neither randomized nor blinded. Formal interim analyses are not planned.
STATISTICS **Primary Analysis Plan**	We will compare the distribution of D_6-$25(OH)D_3$ clearance measured during this study to the distribution of D_6-$25(OH)D_3$ clearance measured in the same participants in the un-supplemented state during CLEAR or CLEAR-CF. We will use the paired t-test to test differences in these distributions. We will use linear regression with multiplicative interaction terms to explore whether CKD or CF modify the D_6-$25(OH)D_3$ clearance response to vitamin D_3 supplementation.
Rationale for Number of Subjects	With 20 participants, we can detect differences in D_6-$25(OH)D_3$ clearance that are small (17.5-55 mL/min depending on assumptions) compared to the mean value observed in CLEAR (351 mL/min) and compared to the change in clearance we expect based on preliminary data (>50%).

1 BACKGROUND

Vitamin D supplementation improves bone mineral density, helps prevent fracture in high-risk populations, and may promote other aspects of health.[1] The broad potential health benefits of vitamin D are currently being tested in large clinical trials, such as the Vitamin D and Omega-3 Trial (VITAL). Circulating concentrations of 25-hydroxyvitamin D [25(OH)D] are currently the most widely accepted tool used to gauge the need for and response to vitamin D supplements. However, large inter-individual differences in circulating 25(OH)D concentration and the 25(OH)D response to vitamin D supplementation are well documented. Furthermore, 25(OH)D is itself relatively inactive, and circulating 25(OH)D concentrations reflect only substrate available for conversion to the 1,25-dihydroxyvitamin D [1,25$(OH)_2$D], the active vitamin D hormone.

Vitamin D clearance is an important and often overlooked aspect of vitamin D biology. Known clinical determinants of circulating 25(OH)D concentration, including dietary intake, sun exposure, adiposity, and race, focus almost entirely on vitamin D intake/production. These factors explain a minority of variability in circulating 25(OH)D concentration and the response to vitamin D supplementation. By definition, steady-state circulating concentrations of 25(OH)D are determined by both intake/production and clearance. Genetic heterogeneity in CYP24A1, the cytochrome P450 enzyme primarily responsible for 25(OH)D clearance, is also a known determinant of circulating 25(OH)D concentration. Our preliminary data suggest that vitamin D supplementation induces CYP24A1-mediated 25(OH)D clearance, and that kidney function may be an important determinant of the 25(OH)D clearance response to vitamin D supplementation.

The proposed studies will provide insight into the biology of 25(OH)D clearance that is likely to enhance interpretation of available diagnostic tests, inform the results of ongoing large clinical trials of vitamin D supplements, and help develop new strategies to target vitamin D to improve health.

1.1 Overview of Clinical Studies

Deuterated and tritiated 25(OH)D_3 have been used previously to study metabolism of vitamin D_3 in humans.[2-6] In addition deuterium is has been used extensively to study metabolism and is considered safe.[7]

2 STUDY RATIONALE

Vitamin D may promote health through pleiotropic actions. Traditionally understood as a calcium regulatory hormone, 1,25-dihydroxyvitamin D (1,25$(OH)_2$D, the potent hormonal form of vitamin D) binds to its target receptor to regulate the transcription of hundreds of genes.[1-8] Vitamin D receptors are present in all nucleated cells in the body, and activation of vitamin D receptors modulates cellular processes related to proliferation, differentiation, fibrosis, cancer, cardiovascular diseases, and other chronic diseases.[6-10] For each of these processes, large effects have been demonstrated in cell culture and animal-experimental models, and clinical epidemiology studies have observed associations of circulating vitamin D metabolite concentrations with clinical health outcomes. As an example, for cardiovascular diseases, 1,25$(OH)_2$D and analogues promote nitric oxide-mediated endothelial vasodilation,[11-16] down-regulate vascular smooth muscle cell proliferation and migration into the intima,[17] inhibit osteogenic differentiation of vascular smooth muscle cells,[18] inhibit macrophage cholesterol uptake and foam cell formation,[19-21] promote a shift from atherogenic Th1 to anti-atherogenic

Th2 lymphocytes,[22] reduce the development and progression of ventricular hypertrophy,[23-27] mitigate cardiac fibrosis,[27-30] and suppress the renin-angiotensin system in animal-experimental models.[31-33] Cardioprotective biological actions of vitamin D are further supported by associations of low serum 25-hydroxyvitamin D [25(OH)D] and 1,25$(OH)_2$D concentrations with clinical hypertension, myocardial infarction, stroke, left ventricular hypertrophy, cancer, and mortality.[34-46] The totality of evidence for vitamin D has motivated large clinical trials, currently underway, to test whether vitamin D treatment will reduce the risks of cancer, cardiovascular disease, and other clinical health outcomes in the general population.

Inter-individual differences in serum 25(OH)D concentration and the serum 25(OH)D response to vitamin D supplements are large. The circulating concentration of 25(OH)D is widely accepted as a biomarker of total intake of vitamins D_3 and D_2 (cholecalciferol and ergocalciferol) from cutaneous synthesis and dietary consumption.[1-3] Serum or plasma 25(OH)D concentration increases robustly to vitamin D supplementation or exposure to ultraviolet light. Circulating 25(OH)D concentration is also inversely correlated with a number of health outcomes, including bone mineral density, risk of hip fracture, incident cancer, and cardiovascular events. Therefore, circulating 25(OH)D concentration is used to define vitamin D sufficiency and deficiency. There is a known large variation across individuals and populations in circulating 25(OH)D concentration. Moreover, published trials demonstrate substantial heterogeneity in the biologic response to vitamin D treatment, defined by changes in parathyroid hormone (PTH), intestinal calcium absorption, bone turnover, and bone mineral density.[47] While clinical characteristics such as race (presumably due to differences in cutaneous vitamin D production due to skin pigmentation), sun exposure, dietary intake of vitamin D, and adiposity (presumably due to vitamin D volume of distribution/fat sequestration) are known to be associated with circulating 25(OH)D concentration, they explain a minority of this variation. Additional reasons for differences in 25(OH)D and the 25(OH)D response to supplementation are poorly understood.

Vitamin D clearance plays an important role in vitamin D biology. Concentrations of vitamin D metabolites in blood and tissues must necessarily represent a balance of production and clearance. In health, CYP24A1 is the major enzyme responsible for catabolism of both 25$(OH)D_3$ and 1,25$(OH)_2D_3$ (**Figure 1**).[4,48-54] CYP24A1 is found in most tissues in the body and is rapidly induced by 1,25$(OH)_2D_3$ to prevent 1,25$(OH)_2D_3$ intoxication.[55-57] Polymorphisms in CYP24A1 were found to be associated with circulating 25(OH)D concentration in a genome-wide association study (GWAS).[58] Similarly, in another GWAS, a polymorphism in CYP24A1 showed the strongest association with the circulating concentration of PTH, a hormone known to regulate and be regulated by 1,25$(OH)_2$D.[59] In unpublished data, we found a CYP24A1 polymorphism to also be most strongly associated with the serum concentration of fibroblast growth factor-23, another hormone known to regulate and be regulated by 1,25$(OH)_2$D. Inactivating mutations in CYP24A1 have been found to cause "idiopathic" infantile hypercalcemia, characterized by excess 1,25$(OH)_2$D-mediated intestinal calcium absorption and hypercalcemia,

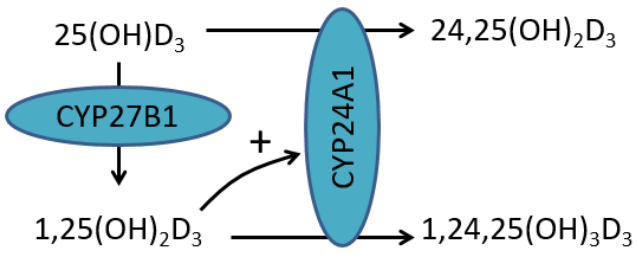

Figure 1. Catabolism of vitamin D_3 metabolites by CYP24A1.

particularly with vitamin D supplementation.[49] These observations demonstrate that vitamin D clearance is critical for maintaining proper vitamin D and calcium homeostasis, perhaps most crucially in the context of vitamin D supplementation.

Serum 24,25(OH)2D3 (or its ratio with 25(OH)D3) maybe a useful novel biomarker of functional vitamin D status. Because CYP24A1 is found in most tissues in the body and is rapidly induced by $1,25(OH)_2D_3$,[55-57] CYP24A1 expression is commonly used as a marker of tissue $1,25(OH)_2D_3$ activity in basic science.[64-80] However, the ability of vitamin D catabolism to reflect $1,25(OH)_2D_3$ function has not been similarly harnessed for clinical use. Evaluation of circulating $24,25(OH)_2D_3$ concentration may offer this opportunity. $24,25(OH)_2D_3$ is the most abundant product of $25(OH)D_3$ catabolism by CYP24A1.[49] When viewed in the context of prevailing $25(OH)D_3$, $24,25(OH)_2D_3$ reflects CYP24A1 activity. $24,25(OH)_2D_3$ circulates at high concentrations (generally 1-10 ng/mL)[81,82] and has a circulating half-life of approximately 7 days.[83] Circulating $24,25(OH)_2D_3$ appears to come from both renal and non-renal sources.[54,67,84-86] In the kidney proximal tubule, CYP24A1 transcription is induced by fibroblast growth factor-23 and suppressed by PTH.[56,87] In our work, we have found chronic kidney disease (CKD, specifically low estimated glomerular filtration rate, or eGFR) to be strongly correlated with serum $24,25(OH)_2D_3$ concentration.

Our preliminary data suggest that vitamin D supplementation increases vitamin D catabolism. We recently published a study assessing the effects of vitamin D_2 (ergocalciferol) supplementation on circulating vitamin D metabolites and vitamin D regulatory hormones.[88] We enrolled 25 participants with CKD (eGFR <60 mL/min/1.73m^2) and 44 participants with eGFR ≥60 mL/min/1.73m^2 and treated each with vitamin D_2 50,000 IU twice weekly for 5 weeks. We measured vitamin D metabolites at baseline and the end of treatment using the precise mass spectrometry methods described in Section 4e of Approach. Among other findings, we reported that vitamin D_2 supplementation significantly increase serum $24,25(OH)_2D_3$ to $25(OH)D_3$ ratio (**Table 2.1**), suggesting induction of $25(OH)D_3$ clearance. We hypothesized that induced clearance contributed to maintenance of normal circulating $1,25(OH)_2D$ concentrations. Notably, the magnitude of increase in $24,25(OH)_2D_3$ to $25(OH)D_3$ ratio was blunted among participants with CKD, suggesting that the decreased $25(OH)D_3$ clearance suggested by low $24,25(OH)_2D_3$ concentrations in our cross-sectional studies extends to the setting of vitamin D_2 supplementation. The use of vitamin D_2 as the supplement allowed us to differentiate exogenous from endogenous vitamin D metabolites, but an important limitation (to be addressed with the proposed studies) was that we could not differentiate true induction of clearance from a shift in available CYP24A1 substrate from $25(OH)D_3$ to $25(OH)D_2$.

Table 2.1. Effects of vitamin D_2 supplementation on serum $24,25(OH)_2D_3$:$25(OH)D_3$ ratio

	Participants with CKD (N=25)	**Participants with normal eGFR (N=44)**
Baseline	72 (9)	116 (8)
End of study	110 (9)	195 (8)
Change	+38 (21 to 56)	+80 (65 to 94)
p-value	<0.001	<0.001
Cell contents are mean (SD) or mean change with supplementation (95% CI) (in pg/ng), or p-value		

In summary, despite widespread interest in vitamin D an intervention to improve diverse aspects of health, little attention has been paid to the role of clearance in vitamin D biology. Clearance is a fundamental component of vitamin D homeostasis and is likely to be an important determinant of both steady state 25(OH)D concentrations and the biologic response to vitamin D supplementation. Our preliminary data suggest that vitamin D clearance induces CYP24A1-mediated 25(OH)D clearance, and that clinical characteristics (e.g. kidney function) modify this response. Our preliminary data further support the concept that circulating $24,25(OH)_2D_3$ concentration is a useful biomarker of CYP24A1-mediated 25(OH)D clearance. However, most studies performed to date, including our own, have used biomarkers to evaluate the effects of vitamin D supplements on vitamin D clearance. In this study, we will use gold standard pharmacokinetic studies to assess the $25(OH)D_3$ clearance response to vitamin D_3 supplementation.

2.1 Risk / Benefit Assessment

This study will not provide any direct benefit to the study subjects. Individual subjects may have a modestly reduced chance of adverse health events because their care will be monitored more closely than it might otherwise. Future patients may benefit from these studies by virtue of knowledge gained about the pathophysiology and ascertainment of impaired vitamin D metabolism.

The risks of administering deuterated $25(OH)D_3$ in tracer quantities are low. $25(OH)D_3$ is a naturally occurring substance and generally circulates in concentrations of 10-50 ng/mL. The deuterated $25(OH)D_3$ we propose to administer differs from the naturally occurring form only by the substitution of 6 hydrogen atoms with deuterium. This isotope is stable and has metabolic and biologic characteristics identical to the naturally occurring form. We will administer quantities intended to make small changes in total circulating $25(OH)D_3$ concentration, i.e., an increase of 5 ng/mL.

There is some risk of hypercalcemia with the administration $25(OH)D_3$, but this risk is minimized by excluding participants with baseline 25(OH)D > 50 ng/mL and by administering quantities that raise 25(OH)D by only approximately 5 ng/mL. We will monitor for hypercalcemia during our research. If instances of hypercalcemia are observed, we will change our study protocol accordingly to prevent hypercalcemia in future participants. Moreover, this protocol will only enroll participants who successfully completed a related protocol (CLEAR or CLEAR-CF) without adverse effect. This study also includes placement of peripheral intravenous catheters and blood draws. Risks include discomfort at the site of administration, minor bleeding associated with catheter placement, and anemia due to blood sampling.

3 STUDY OBJECTIVES

3.1 Primary Objective

The goal of this study is to determine whether $25(OH)D_3$ clearance is affected by vitamin D_3 supplementation. The data obtained in this study will be compared to previously obtained "un-supplemented" measurements taken in the same patients. Only subjects who previously participated in the CLEAR or CLEAR-CF protocol and from whom un-supplemented, measurements of $25(OH)D_3$ clearance were obtained will be enrolled in this study.

3.2 Secondary Objectives

- To explore whether disease status (chronic kidney disease or cystic fibrosis) modify the 25(OH)D_3 clearance response to vitamin D_3 supplementation.
- To evaluate biomarkers of 25(OH)D_3 clearance during vitamin D_3 supplementation.

4 STUDY DESIGN

This is a single-dose, open-label pharmacokinetic study that uses intravenous administration of a stable deuterium-labeled 25(OH)D_3 to evaluate the metabolic clearance of 25(OH)D_3 in subjects supplementing their diet with a stable dose of vitamin D_3. This study will enroll up to 20 subjects who previously participated in the CLEAR or CLEAR-CF protocol and from whom un-supplemented measurements of 25(OH)D_3 clearance were obtained.

Subjects who qualify and provide written informed consent will be prescribed a stable, standard dose of vitamin D_3 supplement (cholecalciferol, 2000 IU daily by mouth), to be taken throughout the duration of the study (approximately 6 months).

After 3 months of vitamin D_3 run-in, participants will be re-screened for eligibility (prior to receiving the intravenous labeled 25(OH)D_3 study drug). Participants who remain eligible at re-screening will receive a single dose of intravenous labeled 25(OH)D_3. Subsequent blood draws and urine collections will be used to determine the metabolic clearance of 25(OH)D_3 and related parameters. The metabolic clearance of 25(OH)D_3 during stable vitamin D_3 supplementation (obtained from this protocol) will be compared to the metabolic clearance of 25(OH)D_3 in the un-supplemented state (obtained for the same participants during CLEAR or CLEAR-CF) to assess the effects of vitamin D_3 supplementation.

5 CRITERIA FOR EVALUATION

5.1 Primary Efficacy Endpoint

The primary outcome of interest is the metabolic clearance of labeled 25(OH)D_3.

We will measure serum concentrations of 24,25$(OH)_2D_3$, 25(OH)D_3, 25(OH)D_2, 1,25$(OH)_2D_3$ and 1,25$(OH)_2D_2$ at the University of Washington by mass spectrometry For each participant and time point, a single serum aliquot is used to measure this panel of vitamin D metabolites using by immunoaffinity extraction and HPLC-mass spectrometry (Xevo TQ, Waters Corp., Milford, MA) with deuterated internal standards.[53-56]

For each subject, non-compartmental analysis of plasma concentration versus time data will be performed using Phoenix software (Pharsight, Cary, NC). Clearance will be calculated as administered 25(OH)D_3 dose divided by 25(OH)D_3 AUC. We focus on clearance as our primary outcome because it reflects the metabolism of 25(OH)D_3 accounting for circulating 25(OH)D_3 concentration (units of volume/time, akin to creatinine clearance). Clearance is independent of volume of distribution, in contrast to $t_{1/2}$, which will be evaluated as a secondary outcome. Clearance will be evaluated with and without adjustment for body size.

5.2 Secondary Efficacy Endpoints

- AUC of labeled D_6-25(OH)D_3
- Terminal half-life of labeled D_6-25(OH)D_3

- Volume of distribution in the central compartment of labeled D_6-25(OH)D_3
- Metabolic formation clearance (metabolite/parent AUC ratio) for metabolites of labeled D_6-25(OH)D_3

5.3 Safety Evaluations

An abnormal clinical laboratory value will be documented as an adverse event if one of the following applies:

- The abnormality is not contradicted by a repeat test to confirm the abnormality.
- The abnormality suggests a disease and/or organ toxicity.
- The abnormality is of a degree that requires active management (e.g., requires a medication change, more frequent follow-up, or further diagnostic evaluation).

Change in clinical laboratory findings (if there are specific labs, then why they are appropriate to measure, e.g., BUN or Creatinine for an aminoglycoside)

An adverse event (AE) is any symptom, sign, illness or experience that develops or worsens in severity during the course of the study. Intercurrent illnesses or injuries should be regarded as adverse events. Abnormal results of diagnostic procedures are considered to be adverse events if the abnormality:

- results in study withdrawal
- is associated with a serious adverse event
- is associated with clinical signs or symptoms
- leads to additional treatment or to further diagnostic tests
- is considered by the investigator to be of clinical significance

A serious adverse event is any AE that is:

- fatal
- life-threatening
- requires or prolongs hospital stay
- results in persistent or significant disability or incapacity
- a congenital anomaly or birth defect
- an important medical event

Important medical events are those that do not fit the other definitions of serious adverse events, but the event may jeopardize the patient and may require treatment to prevent one of the listed serious adverse events.

Adverse events will be reported if they occur between the time of informed consent and 30 days after the last study visit. All unresolved adverse events will be followed by the PI until resolution, the adverse event is otherwise explained, or the participant is lost to follow-up. At the last study visit, the investigator will instruct each participant to report any subsequent event that the participant, or participant's personal physician, reasonably believes may be related to the study. The investigator will notify the study sponsor of any death or adverse event occurring after the participant has discontinued participation if the event can be reasonably related to the study.

6 SUBJECT SELECTION

6.1 Study Population

Only participants who successfully completed the CLEAR or CLEAR-CF protocol will be eligible for this study. CLEAR and CLEAR-CF are single-center studies that recruit adults with and without chronic kidney disease (for CLEAR) or with or without cystic fibrosis (for CLEAR-CF) from the University of Washington system and related institutions. CLEAR or CLEAR-CF participants will be approached for participation in this study at the time of their last CLEAR or CLEAR-CF visit, or within 18 months of completing the CLEAR or CLEAR-CF protocol.

6.2 Inclusion Criteria

The main inclusion criterion is the successful completion of related protocol CLEAR or CLEAR-CF, defined as:

- Receipt of D_6-25-hydroxyvitamin D_3 Solution under the CLEAR or CLEAR-CF protocol,
- Completion of at least 7 CLEAR or CLEAR-CF study visits, and
- Absence of adverse events related to D_6-25-hydroxyvitamin D_3 Solution administration during participation in CLEAR or CLEAR-CF

CLEAR and CLEAR0CF enrolled only adults, with additional eligibility criteria related to race, disease status (stage of chronic kidney disease or presence of cystic fibrosis), and screening serum 25(OH)D concentration (10-50 ng/mL).

6.3 Exclusion Criteria

Exclusion criteria will be:

- Inability to give informed consent
- Primary hyperparathyroidism
- Gastric bypass
- Tuberculosis or sarciodosis
- pregnancy
- Child-Pugh Class B or C cirrhosis (i.e. cirrhosis with ascites, hepatic encephalopathy, bilirubin >=2 mg/dL, serum albumin <=3.5 g/dL, or PT >= 4 seconds)
- History of kidney transplantation (unless failed transplant now treated with hemodialysis)
- hemoglobin <9 mg/dL
- serum calcium >10.1 mg/dL
- use of active vitamin D receptor agonists (e.g. $1,25(OH)_2D_3$ or an analogue, calcitriol) or cinacalcet within 4 weeks
- use of a cytochrome P-450 (CYP) inhibitor or inducer within 4 weeks (table 6.4)
- Unwilling to take vitamin D_3 (cholecalciferol) 2000 IU daily by mouth, as provided by the study

If people do not meet eligibility criteria based on medication use, they will be allowed to participate in the study after an appropriate washout period if their primary physician agrees. For active vitamin D compounds, cinacalcet, and CYP inhibitors and inducers the washout period will be 4 weeks.

Table 6.3. Patient Eligibility – Exclusion criteria
Active vitamin D receptor agonist (e.g. calcitriol) or cinacalcet in last 4 weeks
Child-Pugh Class B or C cirrhosis
Hemoglobin < 9 mg/dl
Serum calcium concentration > 10.1 mg/dl
Pregnancy
Inability to give informed consent
Medications known to strongly induce or suppress the CYP enzymes which metabolize vitamin D (see example list below)

Table 6.4. CYP inhibitors and inducers		
CYP Inhibitors		**CYP Inducers**
Amprenavir	Imatinib	Avasimibe
Aprepitant	Indinavir	Bosentan
Atazanivir	Itraconazole	Carbamazepine
Casopitant	Ketoconazole	Efavirenz
Cimetidine	Lopinavir	Etravirine
Ciprofloxacin	Nefazodone	Modafinil
Clarithromycin	Nelfinavir	Nafcillin
Conivaptan	Posaconazole	Phenobarbital
Darunavir	Ritonavir	Phenytoin
Diltiazem	Saquinavir	Rifabutin
Dronedarone	Shisandra	Rifampin
Elvitegravir	Telithromycin	St. John's Wort
Erythromycin	Tipranavir	
Fluconazole	Verapamil	
Grapefruit Juice*	Voriconazole	

* Greater than 8 ounces per day

7 CONCURRENT MEDICATIONS

All subjects will be asked to take vitamin D_3 (cholecalciferol) 2000 IU daily by mouth, provided by the study. Vitamin D_3 is a common form of vitamin D supplement that is readily available by prescription or over the counter. Vitamin D_3 is administered orally, and 2000 IU daily is a common dose that is well below the tolerable upper intake level advised by the Institute of Medicine (4000 IU daily). This form and dose of vitamin D supplement is being actively studied in large clinical trials with clinical outcomes, such as the Vitamin D and Omega-3 Trial (VITAL), which will increase the utility of the data generated from this study. Hypercalcemia is a rare but known potentially complication of vitamin D_3 supplementation (more commonly at higher doses), so serum calcium will be checked after 3 months of vitamin D_3 supplementation (at the re-screening visit), prior to administration of the deuterated 25(OH)D_3 study drug. Vitamin D_3 will be obtained from Carlson Laboratories; supporting information is supplied in the protocol appendix. Participants will be allowed to take up to 400 IU daily additional vitamin D supplements (as vitamin D_3 or vitamin D_3, alone or as part of a multivitamin) in addition to

the 2000 IU daily provided by the study. Non-study vitamin D supplements exceeding 400 IU daily will be disallowed.

Other specific allowed and disallowed medications are detailed in Section 6 (Eligibility Criteria). All subjects should be maintained on the same medications throughout the entire study period, as medically feasible, with no introduction of new chronic therapies.

8 STUDY TREATMENTS

8.1 Method of Assigning Subjects to Treatment Groups

All consenting and qualified participants will be assigned to the single treatment arm.

8.2 Blinding

Neither participants nor study investigators will be blinded to the study intervention.

8.3 Formulation of Test and Control Products

We will administer labeled D_6-25(OH)D_3 Solution for Injection, 20 µg/mL intravenously. D_6-25(OH) D_3 Solution for Injection, 20 µg/mL has been manufactured according to current Good Manufacturing Practices by SRI International (Palo Alto, CA).

8.3.1 Formulation of Test Product

The labeled D_6-25(OH)D_3 Solution for Injection, 20 µg/mL prepared by SRI International is formulated in cosolvents to enhance solubility. Each mL contains 20 µg D_6-25(OH) D3, 60% propylene glycol (60%), 10% ethanol (ETOH) and water (30%) for injection, to volume.

8.3.2 Packaging and Labeling

The formulated drug product has been aliquoted into single-use vials by SRI International and frozen at <60°C for storage. Vial labels include the drug product name, concentration, batch number, manufacture date, and storage conditions, similar to the draft label shown below.

D_6-25-Hydroxyvitamin D3 Solution for Injection, 20 µg/mL, 5 mL single use vial
Subject ID: _____
Batch No.: 16504-08 Manuf. Date: Sept 2016
Store at ≤ -60°C (- 76°F)
See protocol for preparation for administration instructions
Caution: New Drug -- Limited by Federal (US) law to investigational use.
Keep out of the reach of children.
Manufactured by SRI International, Menlo Park, CA 94025

8.4 Supply of Study Drug at the Site

Single-use vials will be stored at <60°C at the University of Washington Investigational Drug Services or Kidney Research Institute. Individual doses of D_6-25(OH) D_3 Solution for Injection will be prepared for intravenous administration by the University of Washington Investigational Drug Services by thawing and drawing the appropriate volume into a syringe. The prepared dose of will be calculated according to estimated blood volume based on body weight. The prepared

dosing syringe will be labeled with the participant's full name, date of birth, and medical record number along with the drug contents. Once thawed, the drug product will be infused within eight hours of preparation.

8.4.1 Dosage/Dosage Regimen

Each participant will receive a single intravenous dose of D_6-25(OH) D_3 Solution for Injection, 20 µg/mL. We will use estimated blood volume based on body weight to achieve a target concentration of 5 ng/mL D_6-25(OH) D_3. The target of 5 ng/mL was selected because it will allow precise tracking of circulating deuterated D_6-25(OH) D_3concentration throughout follow-up (based on known limits of detection for our assay) without substantially perturbing underlying vitamin D status. Theoretically, the dose required to achieve a 5 ng/mL increment in deuterated 25(OH)D_3 concentration can be calculated as the targeted peak concentration multiplied by the volume of distribution, which for 25(OH)D_3 is expected to be equal to blood volume. We will use the formula of Nadler et al (1962) to estimate blood volume for each participant. We will begin the study by administering to each participant a dose of 5 ng/mL x estimated blood volume. A typical dose would be 32 µg (1.6 mL) for an 85 kg individual. We have verified in CLEAR and CLEAR-CF that we achieve target D_6-25(OH) D_3 concentrations with this approach.

8.4.2 Dispensing

All study drug will be dispensed by the University of Washington Investigational Drug Services.

8.4.3 Administration Instructions

The study drug will be administered intravenously on a single occasion over a period of 5 minutes. Subsequent to thawing, the drug product vial may be stored refrigerated (2-8 °C) for up 24 hours prior to preparation for administration in a syringe. Once prepared for administration and held at room temperature, the solution should be administered within 8 hours.

8.5 Supply of Study Drug at the Site

All single-use vials of formulated D_6-25(OH)D_3 will be shipped overnight on dry ice to the University of Washington Investigational Drug Services, with temperature monitoring. The University of Washington is the sole clinical site for this study.

8.5.1 Storage

Study drug will be securely stored at a temperature <-60°C at the University of Washington Investigational Drug Services or Kidney Research Institute.

8.6 Study Drug Accountability

An accurate and current accounting of the dispensing and return of study drug for each subject will be maintained on an ongoing basis by the University of Washington Investigational Drug Services. The number of study drug dispensed and returned by the subject will be recorded on the Investigational Drug Accountability Record.

8.7 Measures of Treatment Compliance

Each study drug administration will be directly observed by study staff.

9 STUDY PROCEDURES AND GUIDELINES

A Schedule of Events representing the required testing procedures to be performed for the duration of the study is provided in Section 10 (Evaluations by Visit) below and diagrammed in Appendix 1.

Prior to conducting any study-related activities, written informed consent and the Health Insurance Portability and Accountability Act (HIPAA) authorization must be signed and dated by the subject or subject's legal representative. If appropriate, assent must also be obtained prior to conducting any study-related activities.

9.1 Clinical Assessments

9.1.1 Concomitant Medications

All concomitant medication and concurrent therapies will be documented at Screening, Re-screening, Baseline (Study Day 0), and the final Study Visit (Study Visit 10). Dose, route, unit frequency of administration, and indication for administration and dates of medication will be captured.

9.1.2 Demographics

Demographic data will be abstracted from data provided during CLEAR or CLEAR-CF.

9.1.3 Medical History

Relevant medical history, including history of current disease, other pertinent history, and information regarding underlying diseases, will be abstracted from data provided during CLEAR or CLEAR-CF.

9.1.4 Physical Examination

Height and weight will be measured at the Re-screening visit and at Baseline (Study Day 0). When prompted by reports or suspicion of potential adverse effects during follow-up, physical exam findings will be documented by qualified staff (MD, NP, RN, or PA) and will be followed by a physician or other qualified staff immediately or at the next scheduled visit, as indicated.

9.1.5 Vital Signs

Body temperature, blood pressure, pulse and respirations will be measured after resting for 5 minutes at Baseline (Study Day 0), prior to administration of study drug.

9.1.6 Other Clinical Procedures

Physical activity, vitamin D intake, and body composition measured by dual energy X-ray absorptiometry will be abstracted from data provided during CLEAR or CLEAR-CF. Serum and plasma will be collected at Baseline to measure calcium and phosphorus, intact parathyroid hormone, fibroblast growth factor-23, and vitamin D binding protein. Two 24-hour urine collections will be obtained, immediately preceding and following administration of D_6-25(OH)

D3, to quantify urinary excretion of albumin and the metabolites of deuterated D_6-25(OH) D3, respectively. Dialysis patients will be exempt from all urine collections.

9.1.7 Adverse Events

Information regarding occurrence of adverse events will be captured throughout the study. Duration (start and stop dates and times), severity/grade, outcome, treatment and relation to study drug will be recorded on the case report form (CRF).

9.2 Clinical Laboratory Measurements

9.2.1 Hematology

A complete blood count will be obtained at the Re-screening Visit.

9.2.2 Blood Chemistry Profile

Serum sodium, potassium, chloride, bicarbonate, random glucose, BUN, creatinine, aspartate aminotransferase (AST/SGOT), alanine aminotransferase (ALT/SGPT), albumin, calcium, and phosphorous will be obtained at the Re-screening Visit.

Repeat serum sodium, potassium, chloride, bicarbonate, random glucose, BUN, creatinine, aspartate aminotransferase (AST/SGOT), alanine aminotransferase (ALT/SGPT), albumin, calcium, and phosphorous will be obtained at Baseline and Study Day 7.

Intact parathyroid hormone (PTH) will be measured at Visits 2 and 5 (Day 0 and 7 gauged from administration of deuterated 25(OH)D3).

9.2.3 Pregnancy Test

A urine pregnancy test will be obtained from female subjects who are of childbearing age at the Baseline Visit prior to administration of the study drug. For anuric (dialysis) participants, blood pregnancy tests will be obtained to rule out pregnancy during the week preceding the administration of the study drug.

9.3 Pharmacokinetic Measurements

Blood for determination of serum concentrations of deuterated 25(OH)D_3 and its metabolites will be collected at Study Visits 2-10.

At Baseline, blood will be drawn prior to administration of study drug as well as 5 minutes and 4 hours after administration.

9.4 Research Laboratory Measurements

Novel products of 25(OH)D_3 catabolism, including 4β,25(OH)$_2D_3$ and 25(OH)D_3-3-sulfate will be measured using LC-MS/MS, as previously described.[57] 25(OH)D_3-3-sulfate will be extracted from plasma.

10 EVALUATIONS BY VISIT

10.1 Screening Visit (Study Visit 0)

The following activities will occur during the screening visit:

- Collect signed consent form
- Confirm successful completion of CLEAR or CLEAR-CF protocol
- Perform focused medical history restricted to study eligibility criteria
- Complete medication inventory through EMR and patient report
- Participants who meet eligibility criteria at the screening visit will be prescribed vitamin D_3, 2000 IU daily by mouth

10.2 Re-screening Visit (Study Visit 1)

The Re-screening Visit will take place approximately 90 days after the Screening Visit (allowable range 60-180 days). The following activities will occur during the re-screening visit:

- Confirm adherence (≥80%) to study vitamin D_3 (by self-report and pill count)
- Repeat focused medical history restricted to study eligibility criteria
- Complete medication inventory through EMR and patient report.
- Physical Exam (height and weight), and Vital Signs (blood pressure, heart rate)
- Collect non-fasting blood sample for measurement of complete blood count and total 25(OH)D.
- Collect non-fasting blood sample for serum sodium, potassium, chloride, bicarbonate, random glucose, BUN, creatinine, AST/SGOT, ALT/SGPT, albumin, calcium, and phosphorous.
- Participants who continue to meet eligibility criteria, at the screening visit and who are adherent (≥80%) to study vitamin D_3, will be invited to return for the remaining study visits.
- Provide selected subjects with supplies required for first 24-hour urine collection

10.3 Baseline Visit (Study Visit 2, Day 0)

Visit 2 will take place at the University of Washington Clinical Research Center (CRC) or a suitable alternate facility and will last approximately 5 hours. Visit 2 will take place at least 90 days after Visit 0 and no more than 90 days after Visit 1. If more than 90 days elapse between Visits 1 and 2, screening procedures may be repeated to verify continued eligibility. The following activities will occur during the baseline visit:

- Perform a complete medical history
- Review current medications.
- Physical Exam (height and weight), and Vital Signs (blood pressure, heart rate)
- Complete physical activity and food frequency questionnaires.
- Pregnancy test for women of childbearing potential
- Collect blood **prior to administration of study drug** for measurement of basic chemistries, vitamin D metabolites, parathyroid hormone (PTH), and other measurements related to kidney disease and vitamin D metabolism.
- Collect urine sample from first 24-hour collection period. Sample will be used for measurement of albumin, creatinine, vitamin D binding protein, and vitamin D metabolites:
- Administer D_6-25(OH) D3 intravenously.

- Collect blood 5 minutes and 4 hours post-infusion for measurement of vitamin D metabolites.
- Distribute supplies for second 24-hour urine collection.

10.4 Study Visit 3 (Day 1)

This visit is expected to last less than one hour. The following activities will occur during Visit 3:

- Collect urine sample from second 24-hour collection period.
- Collect blood for measurement of serum vitamin D metabolite concentrations.

10.5 Study Visit 4 (Day 4)

This visit is expected to last less than one hour. A window of one day before or after the scheduled date will be allowed when needed. Blood will be collected for measurement of serum vitamin D metabolite concentrations.

10.6 Study Visit 5 (Day 7)

This visit is expected to last less than one hour. A window of one day before or after the scheduled date will be allowed when needed. The following activities will occur during Visit 7:

- Collect blood for measurement of serum vitamin D metabolite concentrations.
- Collect blood for serum sodium, potassium, chloride, bicarbonate, random glucose, BUN, creatinine, aspartate aminotransferase (AST/SGOT), alanine aminotransferase (ALT/SGPT), albumin, calcium, and phosphorous at Study Visit 5 (Day 7) to monitor study safety.

10.7 Study Visits 6-10 (Day 14, 21, 28, 42, and 56)

Each of these visits is expected to last less than one hour. A window of up to 3 days before or after the scheduled date will be allowed when needed. Blood will be collected at each visit for measurement of serum vitamin D metabolite concentrations. Medication inventory will be repeated at Visit 10 (Day 56).

11 ADVERSE EXPERIENCE REPORTING AND DOCUMENTATION

11.1 Adverse Events

An adverse event (AE) is any symptom, sign, illness or experience that develops or worsens in severity during the course of the study. Intercurrent illnesses or injuries should be regarded as adverse events. Abnormal results of diagnostic procedures are considered to be adverse events if the abnormality:

- results in study withdrawal
- is associated with a serious adverse event
- is associated with clinical signs or symptoms
- leads to additional treatment or to further diagnostic tests
- is considered by the investigator to be of clinical significance

11.1.1 AE Severity

The National Cancer Institute's Common Terminology Criteria for Adverse Events (CTCAE) Version 3.0 should be used to assess and grade AE severity, including laboratory abnormalities judged to be clinically significant. The modified criteria can be found in the study manual. If the experience is not covered in the modified criteria, the guidelines shown in Table 11.1 below should be used to grade severity. It should be pointed out that the term "severe" is a measure of intensity and that a severe AE is not necessarily serious.

Table 11.1 AE Severity Grading

Severity (Toxicity Grade)	Description
Mild (1)	Transient or mild discomfort; no limitation in activity; no medical intervention or therapy required. The subject may be aware of the sign or symptom but tolerates it reasonably well.
Moderate (2)	Mild to moderate limitation in activity, no or minimal medical intervention/therapy required.
Severe (3)	Marked limitation in activity, medical intervention/therapy required, hospitalizations possible.
Life-threatening (4)	The subject is at risk of death due to the adverse experience as it occurred. This does not refer to an experience that hypothetically might have caused death if it were more severe.

11.1.2 AE Relationship to Study Drug

The relationship of an AE to the study drug should be assessed using the following the guidelines in Table 11.2.

Table 11.2 AE Relationship to Study Drug

Relationship to Drug	Comment
Definitely	Previously known toxicity of agent; or an event that follows a reasonable temporal sequence from administration of the drug; that follows a known or expected response pattern to the suspected drug; that is confirmed by stopping or reducing the dosage of the drug; and that is not explained by any other reasonable hypothesis.
Probably	An event that follows a reasonable temporal sequence from administration of the drug; that follows a known or expected response pattern to the suspected drug; that is confirmed by stopping or reducing the dosage of the drug; and that is unlikely to be explained by the known characteristics of the subject's clinical state or by other interventions.

Possibly	An event that follows a reasonable temporal sequence from administration of the drug; that follows a known or expected response pattern to that suspected drug; but that could readily have been produced by a number of other factors.
Unrelated	An event that can be determined with certainty to have no relationship to the study drug.

11.2 Serious Adverse Experiences (SAE)

An SAE is defined as any AE occurring at any dose that results in any of the following outcomes:

- death
- a life-threatening adverse experience
- inpatient hospitalization or prolongation of existing hospitalization
- a persistent or significant disability/incapacity
- a congenital anomaly/birth defect

Other important medical events may also be considered an SAE when, based on appropriate medical judgment, they jeopardize the subject or require intervention to prevent one of the outcomes listed.

A serious adverse event is any AE that is:

- fatal
- life-threatening
- requires or prolongs hospital stay
- results in persistent or significant disability or incapacity
- a congenital anomaly or birth defect
- an important medical event

Important medical events are those that do not fit the other definitions of serious adverse events, but the event may jeopardize the patient and may require treatment to prevent one of the listed serious adverse events.

Adverse events will be collected if they occur between the time of informed consent and up to 30 days after the last study visit. All unresolved adverse events will be followed by the PI until resolution, the adverse event is otherwise explained, or the participant is lost to follow-up. At the last study visit, the investigator will instruct each participant to report any subsequent event that the participant, or participant's personal physician, reasonably believes may be related to the study. The investigator will notify the study sponsor of any death or adverse event occurring after the participant has discontinued participation if the event can be reasonably related to the study.

11.3 Abnormal lab values

An abnormal clinical laboratory value will be documented as an adverse event if one of the following applies:

1. The abnormality is not contradicted by a repeat test to confirm the abnormality.

2. The abnormality suggests a disease and/or organ toxicity.
3. The abnormality is of a degree that requires active management (e.g., requires a medication change, more frequent follow-up, or further diagnostic evaluation).

11.4 Hospitalization, Prolonged Hospitalization or Surgery

Any adverse event that results in hospitalization or prolonged hospitalization will be documented and reported as a serious adverse event unless specifically instructed otherwise in this protocol. Any condition responsible for surgery will be documented as an adverse event if the condition meets the criteria for and adverse event. Neither the condition, hospitalization, prolonged hospitalization, nor surgery are reported as an adverse event in the following circumstances:

1. Hospitalization or prolonged hospitalization for diagnostic or elective surgical procedures for a preexisting condition. Surgery should not be reported as an outcome of an adverse event if the purpose of the surgery was elective or diagnostic and the outcome was uneventful.
2. Hospitalization or prolonged hospitalization required to allow efficacy measurement for the study.
3. Hospitalization or prolonged hospitalization for therapy of the target disease of the study, unless it is a worsening or increase in frequency of hospital admissions as judged by the clinical investigator.

11.2.1 Serious Adverse Experience Reporting

The PI will document all SAEs that occur (whether or not related to study drug) on an SAE Report Form. The collection period for all SAEs will begin after informed consent is obtained until all procedures for the final study visit have been completed.

All SAE Report Forms will be reviewed by the PI. SAE reports that are both related and unexpected will be sent to FDA within one business day of learning of the event. SAE reports that are both related and unexpected will also be forwarded to the UW Institutional Review Board, in accordance with UW Standard Operating Procedures. Because this is an observational study, no data safety and monitoring board will be created for this trial. Adverse events and recruitment will be monitored by the PI and reported to the UW IRB, as described above.

12 DISCONTINUATION AND REPLACEMENT OF SUBJECTS

12.1 Early Discontinuation of Study Drug

A subject may be discontinued from study treatment at any time if the subject, the investigator, or the Sponsor feels that it is not in the subject's best interest to continue. The following is a list of possible reasons for study treatment discontinuation:

- Subject withdrawal of consent
- Subject is not compliant with study procedures
- Adverse event that in the opinion of the investigator would be in the best interest of the subject to discontinue study treatment
- Protocol violation requiring discontinuation of study treatment

- Lost to follow-up
- Sponsor request for early termination of study
- Positive pregnancy test (females)

If a subject is withdrawn from treatment due to an adverse event, the subject will be followed and treated by the Investigator until the abnormal parameter or symptom has resolved or stabilized.

All subjects who discontinue study treatment should come in for an early discontinuation visit as soon as possible and then should be encouraged to complete all remaining scheduled visits and procedures.

All subjects are free to withdraw from participation at any time, for any reason, specified or unspecified, and without prejudice.

Reasonable attempts will be made by the investigator to provide a reason for subject withdrawals. The reason for the subject's withdrawal from the study will be specified in the subject's source documents Refer to Section 10 for early termination procedures.

12.3 Withdrawal of Subjects from the Study

A subject may be withdrawn from the study at any time if the subject, the investigator, or the Sponsor feels that it is not in the subject's best interest to continue.

All subjects are free to withdraw from participation at any time, for any reason, specified or unspecified, and without prejudice.

Reasonable attempts will be made by the investigator to provide a reason for subject withdrawals. The reason for the subject's withdrawal from the study will be specified in the subject's source documents. Subjects who withdraw after Visit 2 but prior to Visit 10 will be encouraged to come in for a final visit (and the procedures to be followed would include those for their next scheduled visit).

12.4 Replacement of Subjects

Subjects who withdraw from the study treatment will be replaced.

Subjects who withdraw from the study will be replaced.

13 PROTOCOL VIOLATIONS

A protocol violation occurs when the subject or Sponsor-Investigator fails to adhere to significant protocol requirements affecting the inclusion, exclusion, subject safety and primary endpoint criteria. Protocol violations for this study include, but are not limited to, the following:

- Failure to meet inclusion/exclusion criteria
- Use of a prohibited concomitant medication
- Failure to comply with Good Clinical Practice (GCP) guidelines will also result in a protocol violation. The Sponsor-Investigator will determine if a protocol violation will result in withdrawal of a subject.

When a protocol violation occurs, it will be discussed with the Sponsor-Investigator and a Protocol Violation Form detailing the violation will be generated. This form will be signed by a

Sponsor-Investigator. A copy of the form will be maintained in the regulatory binder and in the Sponsor-Investigator's files.

14 STATISTICAL METHODS AND CONSIDERATIONS

14.1 Data Sets Analyzed

All participants who receive the study drug (D_6-25(OH) D3 Solution for Injection) will be included in the safety analysis.

14.2 Demographic and Baseline Characteristics

The following variables collected at re-screening will be summarized: age, gender, medical comorbidities, medications used, height, weight, body mass index, laboratory values (including calcium, phosphorus, albumin, vitamin D binding protein, parathyroid hormone, fibroblast growth factor-23), and adiposity measured by DXA.

14.3 Analysis of Primary Endpoint

We will compare the distribution of D_6-25(OH)D_3 clearance measured during this study to the distribution of D_6-25(OH)D_3 clearance measured in the same participants in the unsupplemented state during CLEAR or CLEAR-CF. We will use the paired t-test to test differences in these distributions. We will use linear regression with multiplicative interaction terms to explore whether CKD or CF modify the D_6-25(OH)D_3 clearance response to vitamin D_3 supplementation..

14.4 Analysis of Secondary Endpoints

Analyses of secondary endpoints will parallel those of the primary endpoint.

14.5 Interim Analysis

This is not a clinical trial with an efficacy outcome, and it is neither randomized nor blinded. No formal interim analyses are planned.

14.6 Sample Size and Randomization

The sample size of 20 participants gives us excellent power to detect even modest differences in 25(OH)D_3 clearance with vitamin D_3 supplementation. To determine detectable effect sizes using a fixed sample size of 20 participants, a pre-post design using the paired t-test, 90% power, and a type 1 error rate of 5%, we assumed that the standard deviation of baseline deuterated 25(OH)D_3 clearance observed among our first four actual participants (319, 322, 332, and 431 mL/day) was the same as that of supplemented clearance. We calculated the minimal detectable differences in deuterated 25(OH)D_3 clearance (i.e. the smallest differences we can detect with 90% power; power is >90% for larger differences),over a range of correlation for baseline and supplemented clearance (a factor that is unknown). **Table 14.1** shows that we can detect differences in clearance that are small compared to the mean value for our first four participants (351 mL/day) and compared to the change in clearance we expect (>50% increase, as per preliminary study reported in Table 2.1).

Table 14.1. Study power	
Correlation of baseline and supplemented clearances	**Minimal detectable difference with 90% power (mL/day)**
r = 0	55
r = 0.25	48
r = 0.5	39
r = 0.75	27.5
r = 0.9	17.5

15 DATA COLLECTION, RETENTION AND MONITORING

15.1 Data Collection Instruments

The PI will prepare and maintain adequate and accurate source documents designed to record all observations and other pertinent data for each subject treated with the study drug. Study personnel at each site will enter data from source documents corresponding to a subject's visit into the protocol-specific electronic Case Report Form (eCRF) when the information corresponding to that visit is available. Subjects will not be identified by name in the study database or on any study documents to be collected by the Sponsor (or designee), but will be identified by a subject number. The Investigator is responsible for all information collected on subjects enrolled in this study. All data collected during the course of this study must be reviewed and verified for completeness and accuracy by the Investigator.

15.2 Data Management Procedures

The data will be entered into a validated database. Database lock will occur once quality assurance procedures have been completed.

All procedures for the handling and analysis of data will be conducted using good computing practices meeting FDA guidelines for the handling and analysis of data for clinical trials.

15.3 Data Quality Control and Reporting

After data have been entered into the study database, a system of computerized data validation checks will be implemented and applied to the database on a regular basis. Queries are entered, tracked, and resolved through the EDC system directly. The study database will be updated in accordance with the resolved queries. All changes to the study database will be documented.

15.4 Archival of Data

The database is safeguarded against unauthorized access by established security procedures; appropriate backup copies of the database and related software files will be maintained. Databases are backed up by the database administrator in conjunction with any updates or changes to the database.

At critical junctures of the protocol (e.g., production of interim reports and final reports), data for analysis is locked and cleaned per established procedures.

15.5 Availability and Retention of Investigational Records

The PI will make study data accessible to the UW monitor, other authorized representatives of the University of Washington IRB, and Regulatory Agency (e.g., FDA) inspectors upon request. A file for each subject will be maintained that includes the signed Informed Consent and HIPAA

Authorization and copies of all source documentation related to that subject. The Sponsor-Investigator will ensure the reliability and availability of source documents from which the information on the CRF was derived.

All study documents (patient files, signed informed consent forms, copies of CRFs, Study File Notebook, etc.) will be maintained for at least two years after the study is completed.

15.6 Monitoring

Study Monitoring Plan. The PI will allocate adequate time for such monitoring activities. The PI will also ensure that any compliance or quality assurance reviewer is given access to all the above noted study-related documents and study related facilities (e.g. diagnostic laboratory), and has adequate space to conduct a monitoring visit, if requested.

Monitoring visits will be conducted by representatives of the University of Washington according to the U.S. CFR Title 21 Parts 50, 56, and 312 and ICH Guidelines for GCP (E6).

15.7 Subject Confidentiality

In order to maintain subject confidentiality, only a subject number will identify all study subjects on CRFs and other documentation submitted to the Sponsor.

16 ADMINISTRATIVE, ETHICAL, REGULATORY CONSIDERATIONS

The study will be conducted according to the Declaration of Helsinki, Protection of Human Volunteers (21 CFR 50), Institutional Review Boards (21 CFR 56), and Obligations of Clinical Investigators (21 CFR 312).

To maintain confidentiality, all laboratory specimens, evaluation forms, reports and other records will be identified by a coded number and initials only. All study records will be kept in a locked file cabinet and code sheets linking a patient's name to a patient identification number will be stored separately in another locked file cabinet. Clinical information will not be released without written permission of the subject, except as necessary for monitoring by the FDA. The Investigator must also comply with all applicable privacy regulations (e.g., Health Insurance Portability and Accountability Act of 1996, EU Data Protection Directive 95/46/EC).

16.1 Protocol Amendments

Any amendment to the protocol will be written by the Investigator-Sponsor. Protocol amendments will not be implemented without prior submission to FDA and prior written IRB approval except as necessary to eliminate immediate safety hazards to patients. A protocol amendment intended to eliminate an apparent immediate hazard to patients may be implemented immediately, provided the IRBs are notified within five working days.

16.2 Institutional Review Boards and Independent Ethics Committees

The protocol and consent form will be reviewed and approved by the University of Washington Institutional Review Board prior to study initiation. Serious adverse experiences regardless of causality will be reported to the IRB in accordance with the standard operating procedures and policies of the IRB, and the Investigator will keep the IRB informed as to the progress of the study. The Investigator will obtain assurance of IRB compliance with regulations.

Any documents that the IRB may need to fulfill its responsibilities (such as protocol, protocol amendments, Investigator's Brochure, consent forms, information concerning patient recruitment, payment or compensation procedures, or other pertinent information) will be submitted to the IRB. The IRB"s written unconditional approval of the study protocol and the informed consent form will be in the possession of the Investigator before the study is initiated. The IRBs unconditional approval statement will be transmitted by the Investigator to the Sponsor or designee prior to the shipment of study supplies to the site. This approval must refer to the study by exact protocol title and number and should identify the documents reviewed and the date of review.

Protocol and/or informed consent modifications or changes may not be initiated without prior written IRB approval except when necessary to eliminate immediate hazards to the patients or when the change(s) involves only logistical or administrative aspects of the study. Such modifications will be submitted to the IRB and written verification that the modification was submitted and subsequently approved should be obtained.

The IRB must be informed of revisions to other documents originally submitted for review; serious and/or unexpected adverse experiences occurring during the study in accordance with the standard operating procedures and policies of the IRB; new information that may affect adversely the safety of the patients of the conduct of the study; an annual update and/or request for re-approval; and when the study has been completed.

16.3 Informed Consent Form

Informed consent will be obtained in accordance with the Declaration of Helsinki, ICH GCP, US Code of Federal Regulations for Protection of Human Subjects (21 CFR 50.25[a,b], CFR 50.27, and CFR Part 56, Subpart A), the Health Insurance Portability and Accountability Act (HIPAA, if applicable), and local regulations.

The Investigator will prepare the informed consent form, assent and HIPAA authorization and provide the documents to the Sponsor or designee for approval prior to submission to the IRB/IEC. The consent form generated by the Sponsor-Investigator must be approved by the IRB/IEC. The written consent document will embody the elements of informed consent as described in the International Conference on Harmonisation and will also comply with local regulations.

A properly executed, written, informed consent will be obtained from each subject prior to entering the subject into the trial. Information should be given in both oral and written form and subjects must be given ample opportunity to inquire about details of the study. If a subject is unable to sign the informed consent form (ICF) and the HIPAA authorization, a legal representative may sign for the subject. A copy of the signed consent form (and assent) will be given to the subject and the original will be maintained with the subject's records.

16.4 Publications

The publication or presentation of any study results shall comply with all applicable privacy laws, including, but not limited to, the Health Insurance Portability and Accountability Act of 1996.

16.5 References

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APPENDIX 1. SCHEDULE OF STUDY PROCEDURES

Procedure	**VISIT 0 SCREENING**	**VISIT 1 RE-SCREENING**	**VISIT 2 BASELINE (DAY 0)**	**VISIT 3 DAY 1**	**VISIT 4 DAY 4**	**VISIT 5 DAY 7**	**VISIT 6 DAY 14**	**VISIT 7 DAY 21**	**VISIT 8 DAY 28**	**VISIT 9 DAY 42**	**VISIT 10 DAY 56**
Informed Consent	**X**	**X**									
Focused Medical History	**X**	**X**									
Physical Exam and Vital Signs		**X**	**X**								
Medications Inventory	**X**	**X**	**X**								**X**
Blood Samples*		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
24-hour urine collections			**X**	**X**							
DNA collection			**X**								
Prescribe vitamin D_3	**X**										
Study Drug Administration			**X**								

*Blood Draws Detailed in Appendix 2.

APPENDIX 2. DRAFT BLOOD DRAW TYPES AND VOLUMES

Blood sample	**VISIT 1 SCREENING**	**VISIT 2 BASELINE (DAY 0)**	**VISIT 3 DAY 1**	**VISIT 4 DAY 4**	**VISIT 5 DAY 7**	**VISIT 6 DAY 14**	**VISIT 7 DAY 21**	**VISIT 8 DAY 28**	**VISIT 9 DAY 42**	**VISIT 10 DAY 56**	**TOTAL VOLUME (ML)**
Clinical lab: CBC (3 mL EDTA-plasma [purple top])	**X**										**3**
Clinical lab: chemistries (4 mL serum [lime green top, PST])	**X**	**X**			**X**						**12**
Clinical lab: total 25(OH)D (4 mL serum [lime green top, PST])	**X**										**4**
Clinical lab: PTH*		**X**			**X**						**0***
Vitamin D metabolites (10 mL serum [red top])		**X****	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**114**
Stored blood (10 mL EDTA-plasma [purple top])		**X**									**10**
DNA***		**X**									**0****
Total volume (mL)	**11**	**48**	**10**	**10**	**14**	**10**	**10**	**10**	**10**	**10**	**143**

Notes: * PTH measured with chemistries, requires no additional volume; ** 14 mL serum prior to injection of D6-25(OH)D_3 plus two 10 mL serum samples after injection of D6-25(OH)D_3; ***DNA extracted from EDTA plasma vacutainer, requires no additional volume