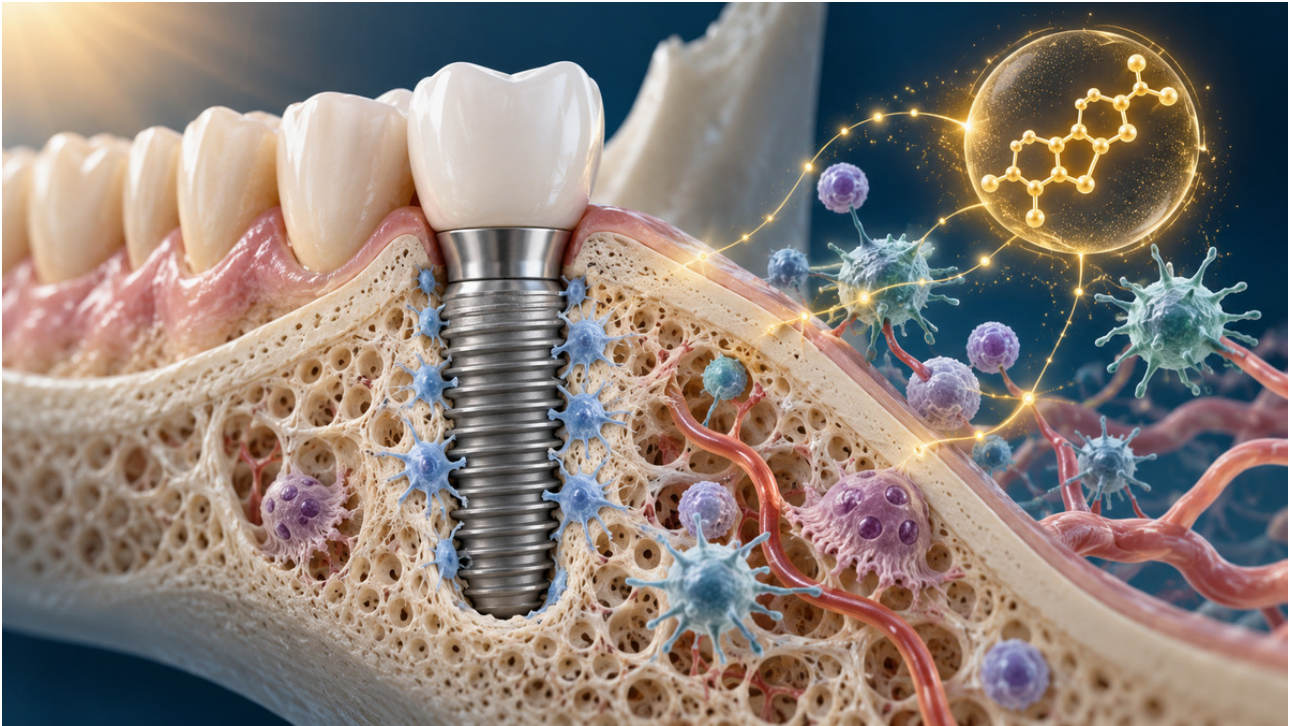


Vitamin D and the Bone-Immune Interface in Implant Healing

Physiology, 25-hydroxyvitamin D interpretation, clinical evidence and safe supplementation boundaries



Core message: vitamin D participates in mineral homeostasis, immune regulation and bone remodelling. Biological plausibility does not justify routine testing of every implant candidate, a universal dental target or high-dose supplementation without a medical indication.

Educational material for dental students, postgraduate trainees and academic teachers

Vitamin D physiology in context

Vitamin D is a fat-soluble prohormone obtained through cutaneous synthesis, food and supplements. Vitamin D3 and D2 undergo hepatic 25-hydroxylation to form 25-hydroxyvitamin D, the main circulating status marker. The kidney and several extra-renal tissues can convert it to active 1,25-dihydroxyvitamin D.

Component	Principal role	Interpretive boundary
Vitamin D3 and D2	Precursors from skin, diet or supplements.	Intake does not predict serum status precisely because sun exposure, absorption and body composition differ.
25(OH)D	Main circulating marker used to assess vitamin D status.	Assay variability and different guideline thresholds affect classification.
1,25(OH)2D	Active ligand that regulates gene transcription through the vitamin D receptor.	Usually unsuitable for routine status assessment because PTH, calcium, phosphate and kidney function tightly regulate it.
Parathyroid hormone	Maintains calcium balance and influences renal activation of vitamin D.	Elevation may reflect vitamin D deficiency, CKD, calcium intake or other causes.
Calcium and phosphate	Mineral substrates for skeletal mineralization.	Serum concentrations do not directly quantify jawbone quality.

A regulated endocrine system

PTH, calcium, phosphate, fibroblast growth factor 23 and kidney function shape vitamin D metabolism. Liver disease, malabsorption, obesity, medication and reduced sun exposure can also alter status. A single 25(OH)D value should therefore be interpreted within the medical context.

Unit check: 25(OH)D is reported in ng/mL or nmol/L. One ng/mL equals 2.5 nmol/L. Milligrams per millilitre are not an appropriate clinical unit.

VDR signalling and osteoimmunology

Active vitamin D binds the vitamin D receptor, which forms a heterodimer with the retinoid X receptor. The complex interacts with vitamin D response elements and modifies transcription in many tissues. The response depends on cell type, differentiation stage, local cytokines and mineral availability.

Cell or pathway	Vitamin D-related biology	Relevance to implant healing
Osteoblast lineage	Influences differentiation, matrix proteins and signals that regulate osteoclast formation.	Supports coordinated matrix production and remodelling rather than bone formation alone.
Osteoclast lineage	Effects are largely indirect through osteoblast-lineage RANKL and osteoprotegerin signalling, with additional immune interactions.	Controlled resorption is necessary for remodelling of injured bone.
Osteocytes	Participate in mineral sensing and remodelling signals such as FGF-23 and sclerostin pathways.	Connect mechanical loading with skeletal adaptation.
Innate immunity	VDR signalling can affect antimicrobial peptides, monocyte and macrophage responses.	Early healing requires defence without persistent destructive inflammation.
Adaptive immunity	Vitamin D can modulate T-cell and antigen-presenting-cell responses.	Mechanistic effects do not prove that supplementation prevents peri-implantitis.

Bone formation and resorption are coupled

Osseointegration requires an initial inflammatory phase, vascular ingrowth, woven bone formation and subsequent remodelling. Osteoblast and osteoclast activity should not be treated as competing good and bad processes. Both are required in the correct sequence and magnitude.

Osteoimmunology is a framework: it explains communication between immune and skeletal cells, but it does not convert one nutrient concentration into a direct prediction of implant success.

What implant research currently supports

Animal experiments commonly report impaired bone-to-implant contact with deficiency and improved histological measures after vitamin D replacement. Human research includes observational cohorts, small trials and case reports. It suggests a possible relationship with early healing, but the evidence remains too heterogeneous for a universal implant-specific threshold or protocol.

Evidence type	Typical finding	Main limitation
Animal studies	Deficiency can impair new bone formation, while supplementation may improve bone-to-implant contact.	Models, doses and induced diseases do not directly represent routine human implant care.
Observational human studies	Lower 25(OH)D sometimes accompanies early failure or less favourable bone outcomes.	Smoking, periodontal history, diabetes, season and supplementation can confound results.
Small clinical trials	Some studies report improved radiographic bone measures or stability after correction.	Sample size, endpoints and supplementation regimens vary.
Case reports	Successful retreatment after correction has been described.	Cannot establish causation or expected benefit.
Systematic reviews	Biological plausibility and a possible positive association are consistent themes.	Few high-quality randomized trials and substantial heterogeneity limit certainty.

Association is not a treatment guarantee

Low vitamin D status may coexist with frailty, low dietary quality, obesity, chronic disease or reduced outdoor activity. Correcting a documented deficiency may support general skeletal health, but it cannot compensate for infection, poor surgical technique, unstable loading or inadequate plaque control.

Clinical boundary: vitamin D status may contribute to the biological context of healing. It is not an independent diagnostic test for osseointegration or peri-implant disease.

Interpreting 25(OH)D without inventing a dental target

Serum 25(OH)D is the standard status marker. Classification differs across organizations and clinical contexts. The Food and Nutrition Board considers less than 12 ng/mL associated with deficiency risk, 12 to less than 20 ng/mL generally inadequate, and 20 ng/mL or more adequate for most healthy people. It also notes potential adverse effects above 50 ng/mL.

25(OH)D concentration	General FNB interpretation	Implant dentistry boundary
<12 ng/mL (<30 nmol/L)	Associated with deficiency and risk of osteomalacia in adults.	Requires medical evaluation and correction, but does not by itself prove that an implant will fail.
12 to <20 ng/mL (30 to <50 nmol/L)	Generally considered inadequate for bone and overall health in healthy people.	Interpret with symptoms, risk factors, bone disease and the planned procedure.
>=20 ng/mL (>=50 nmol/L)	Generally adequate for most healthy people.	No validated implant-specific benefit threshold has been established.
>50 ng/mL (>125 nmol/L)	Linked to potential adverse effects, especially at higher concentrations.	Do not pursue high concentrations as a dental optimization goal.

Why 30 ng/mL is not a universal implant cutoff

Some laboratories and older guidelines use 30 ng/mL as a sufficiency target in selected clinical care. The 2024 Endocrine Society guideline states that outcome-specific thresholds have not been established for generally healthy adults and recommends against routine screening in this population.

Laboratory uncertainty

Assays can yield different results. Season, recent supplementation and biological variation also matter. Repeat testing should answer a treatment question rather than confirm a preferred number.

No automatic cancellation rule: a value between 20 and 29 ng/mL should not automatically cancel implant surgery in an otherwise healthy patient. Evaluate the complete risk profile and medical indication.

Who may need targeted assessment

Routine vitamin D screening of all healthy implant candidates lacks supporting outcome evidence. Testing becomes more reasonable when a result may change medical treatment, clarify a suspected metabolic problem or inform the timing of a major regenerative procedure in a high-risk patient.

Clinical context	Why testing may be relevant	Additional information
Suspected osteomalacia or symptomatic deficiency	Bone pain, muscle weakness or biochemical abnormalities require medical assessment.	Calcium, phosphate, alkaline phosphatase and PTH may be relevant.
Osteoporosis or fragility fracture	Vitamin D forms part of broader skeletal management.	Review antiresorptive therapy, fracture history and bone-health plan.
Chronic kidney disease	Renal activation and CKD-mineral and bone disorder change interpretation.	Use CKD stage, calcium, phosphate, PTH and nephrology guidance.
Malabsorption or bariatric surgery	Reduced fat absorption can impair vitamin D uptake.	Assess nutritional status and the underlying gastrointestinal condition.
Liver disease or selected medication	Metabolism or absorption may be altered.	Coordinate with medical care and review interactions.
Repeated unexplained early implant failure	A targeted metabolic review may identify a correctable systemic factor.	Also reassess infection, biomechanics, smoking and surgical variables.

Procedure complexity can modify the threshold for investigation

Extensive augmentation, multiple implants or a history of impaired healing may justify a broader review than a straightforward single implant in a healthy adult. This is risk-based assessment, not evidence for a universal pre-operative panel.

Test only with a plan: before ordering 25(OH)D, define who will interpret the result, whether treatment is indicated and whether the result could change timing or follow-up.

Supplementation: benefit, dose and safety

Vitamin D treatment belongs within general medical and skeletal care. The dose depends on age, baseline status, diet, absorption, kidney function, comorbidity and concurrent medicines. The implant procedure alone does not justify a fixed high-dose regimen.

Principle	Evidence-based approach	Practice to avoid
Routine intake	Healthy adults should meet age-appropriate dietary reference intakes through food and supplements when needed.	Assuming every implant patient needs pharmacological dosing.
Documented deficiency	Use an established medical treatment regimen with follow-up tailored to the cause and severity.	Prescribing 10,000 IU/day as a universal dental correction dose.
Dosing pattern	When treatment is indicated in adults aged 50 years or older, the Endocrine Society prefers daily lower doses over intermittent high doses.	Large bolus regimens for convenience without a medical reason.
Upper intake level	The adult tolerable upper intake level is 4,000 IU/day for unsupervised chronic intake.	Interpreting the upper limit as a routine target.
Monitoring	Review calcium and 25(OH)D when high-dose treatment, renal disease or another medical risk justifies it.	Repeating broad laboratory panels without a management decision.

Toxicity is a calcium disorder

Excess vitamin D can cause hypercalcaemia and hypercalciuria, with nausea, weakness, polyuria, nephrolithiasis, renal injury, soft-tissue calcification and arrhythmia in severe cases. Granulomatous disease, primary hyperparathyroidism, kidney disease and thiazide treatment require particular caution.

Correction does not prove causation

If a patient with deficiency later heals successfully, that sequence does not establish that vitamin D caused the earlier failure or guaranteed the later success. Local infection, loading, implant position and surgical technique remain essential.

Safety rule: do not initiate prolonged high-dose vitamin D solely to optimize an implant. Coordinate treatment when deficiency or a medical bone disorder is present.

Cofactors without supplement stacking

Magnesium, vitamin K and vitamin A participate in pathways related to mineral metabolism, enzyme activity or nuclear receptor signalling. Their biological roles do not support routine combined supplementation for every implant candidate.

Nutrient	Relevant biology	Clinical boundary
Magnesium	Supports many enzymes and contributes to PTH secretion and vitamin D metabolism.	Supplement only for dietary inadequacy, documented deficiency or another medical indication; renal impairment increases accumulation risk.
Vitamin K	Required for gamma-carboxylation of proteins including osteocalcin.	Evidence does not establish routine K2 supplementation for implant success; vitamin K can interact with vitamin K antagonists.
Vitamin A	Retinoid receptors interact with RXR-dependent nuclear signalling and support normal cell differentiation.	High preformed vitamin A intake can be toxic and may harm bone; do not combine high-dose vitamin A with vitamin D routinely.
Calcium	Provides mineral substrate and supports skeletal health.	Assess diet and medical need; unnecessary supplements can add adverse effects.
Protein and energy	Provide substrates for matrix formation, immune function and tissue repair.	A balanced diet and treatment of malnutrition are more important than an isolated supplement stack.

Cofactors are not antidotes to excessive dosing

Adding K2, magnesium or vitamin A does not neutralize hypercalcaemia or remove the need for dose limits. Combination products can conceal total intake from multiple sources. Record every supplement, including over-the-counter preparations.

Medication reconciliation includes supplements: document product, dose, frequency and reason for use, especially with anticoagulants, kidney disease or pregnancy.

A proportionate clinical pathway

Step	Clinical action	Decision supported
1. Review risk	Assess skeletal disease, kidney or gastrointestinal disease, diet, sun exposure, falls, fractures, medications and prior healing.	Identifies a medical indication for assessment.
2. Define the procedure	Describe implant number, augmentation, expected healing burden and loading plan.	Matches investigation to surgical complexity.
3. Use targeted tests	When indicated, interpret 25(OH)D with calcium, phosphate, PTH, alkaline phosphatase or kidney function as appropriate.	Avoids isolated-number decisions.
4. Coordinate treatment	Refer suspected deficiency, osteomalacia, CKD-MBD or complex supplementation to the responsible clinician.	Protects against unsafe dosing and fragmented care.
5. Reassess timing	Proceed, adapt or defer based on the complete medical and local picture rather than one threshold.	Keeps the implant decision proportionate.
6. Maintain local control	Treat periodontal disease, optimize hygiene, use atraumatic surgery and monitor healing.	Addresses direct drivers of implant outcomes.

Patient communication

Explain that vitamin D supports normal bone and immune physiology, but blood testing does not predict whether an implant will integrate. If deficiency is identified, correction benefits general health and may improve the biological environment. It does not replace local disease control or guarantee success.

Documentation

Record the indication for testing, units, laboratory reference interval, current supplements, the clinician responsible for treatment and the follow-up plan. If implant treatment proceeds before correction is complete, document the rationale and risk discussion.

Balanced explanation: vitamin D is relevant to healing biology, but stronger human trials are still needed to define implant-specific testing and supplementation protocols.

Clinical synthesis and selected references

Clinical synthesis

- Use serum 25(OH)D, not 1,25(OH)₂D, as the usual marker of vitamin D status.
- Interpret 25(OH)D with units, assay context, PTH, calcium, phosphate, kidney function and the clinical indication.
- Do not use 30 ng/mL as a universal implant eligibility threshold.
- Avoid routine screening of every healthy implant candidate.
- Consider targeted testing in metabolic bone disease, malabsorption, CKD or repeated unexplained healing problems.
- Recognize that human implant evidence suggests an association but does not establish a universal protocol.
- Do not prescribe 10,000 IU/day as a standard dental regimen.
- Treat 4,000 IU/day as an adult upper intake level for chronic unsupervised intake, not a routine target.
- Do not add K₂, magnesium or vitamin A automatically.
- Continue to prioritize infection control, surgical technique, stability, loading and maintenance.

Selected references

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Educational use and limitations

This material supports risk-based assessment and interdisciplinary communication. It does not replace diagnosis or treatment of vitamin D deficiency, metabolic bone disease, kidney disease or malabsorption by the responsible clinician.

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