Bone Health: Sound Suggestions for Stronger Bones

11

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Keywords

Bone health · Calcium · Vitamin D · Phosphorus · Magnesium · Protein

Key Points

- Bone requires calcium, vitamin D, protein, and phosphorus for optimal growth and maintenance.
- Food is the best source for most of the nutrients required by bone.
- Many in the population are consuming diets with inadequate calcium, and the elderly may have inadequate protein as well.
- Most adults require additional vitamin D, especially if they have little sun exposure.
- Improvements in nutrition can make a significant difference to bone health, even if started later in life.

Introduction

Bone is a complicated organ made of collagen, proteins, calcium, phosphate, and cells that remodel and maintain it. It requires many nutrients obtained from the diet, or other sources, for remodeling and maintaining the bony structure. Nutrition science has identified a select few of these nutrients as particularly important for bone health. We will highlight those here. However, remember that in food, these nutrients do not occur in isolation; they are present in nature packaged in various combinations of fat, protein, carbohydrate, minerals, etc. Only in the past few decades has it been possible to consume these nutrients in isolation in the form of supplements. As is often the case, the whole is greater than the sum of its parts, and in making recommendations for bone health, we will emphasize obtaining these nutrients from food sources whenever possible.

If a patient is being treated with medication for osteoporosis, we emphasize that these nutrients are the building blocks that the medication uses to form bone. This seems a simplistic concept, but many patients think that the medications themselves contain these nutrients. All bone-active pharmacologic agents have been tested in clinical trials with additional supplemental calcium and most with vitamin D as well. Presumably, the efficacy of the pharmacologic agents depends to some extent on these supplemental nutrients.

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Calcium

For over 100 years, we have been aware of calcium's effects on bone health. Clinical trials using calcium supplements or dairy foods have had either positive or null effects on bone outcomes, that is, greater bone mass during growth, reduced bone loss with age, and reduced fractures. Despite this, controversy and confusion have arisen in recent years as a result of relying on placebo-controlled calcium trials (similar to drug trials). Calcium, as with all nutrients, does not lend themselves well to this type of study design, as there are no placebo diets in a free-living population. A great deal of the results of these types of trials depend on the population studied, and if one examines these trials carefully, one finds that a population of older calcium deficient women, for example, have a greater benefit from supplementation than a dietary calcium replete population. While this makes intuitive sense, some have used null studies to argue against supplementation. Common sense would tell us that adequate calcium intake is necessary and that more is not necessarily beneficial. To put this into context, the National Health and Nutrition Examination Survey (NHANES) 2009–2010 found that 42% of Americans did not meet the estimated average requirements for calcium [1], and that population would likely benefit from increased calcium intake.

The body's calcium requirements have to come from dietary sources. The *blood* level of calcium is tightly maintained despite fluctuations in dietary intake. This constancy is ensured in the face of poor dietary intake by decreasing urinary calcium output, by improving gastrointestinal calcium absorption, and, more importantly, by increasing resorption of bone tissue, thereby releasing its calcium. In brief, *blood* levels of calcium are maintained during long-term dietary calcium deprivation at the expense of the skeleton.

The body systems do not act in isolation: calcium intake and regulation of the calcium economy have effects on other body systems and diseases including hypertension, colon cancer, renolithiasis, obesity, premenstrual syndrome, and polycystic ovary syndrome. However, this review will confine itself to the skeletal effects of calcium (and of nutrition, generally).

Dietary Calcium Requirements

The gut absorbs about 30% of dietary calcium, but the mineral is also lost through gastrointestinal secretions. As a result the net intestinal absorption is only 10–15%. Additionally, calcium is lost in urine and sweat [2, 3]. These so-called obligatory losses amount to about 200 mg/day in adults. Hence, net absorption must be at least that much to maintain zero balance. That much net absorption requires a daily total intake of 1000–1500 mg (the equivalent of 3–5 dairy servings). See Table 11.1.

During growth, net absorption is more efficient, and the bones accumulate mass (and calcium), although when persons consume a low-calcium diet, the bones cannot reach their full potential. Later in life, absorption and retention are less efficient, and the bones are unable to maintain their mass. Calcium retention rises in proportion to the intake up to a certain threshold level, above which excess calcium is excreted. There is no storage mechanism for extra calcium except what is needed by the skeleton.

Table 11.1 Recommended dietary intakes for calcium [4]

Childhood	700–1000 mg
Adolescence	1300 mg
Adult 19–50	1000 mg
Adult 51–70	1000–1200 mg
Adults over 70	1200 mg
Pregnancy	1000–1300 mg
Lactation	1000–1300 mg

Because blood levels of calcium are so tightly regulated, a serum measurement tells one little about the body's calcium intake or reserve. The reserve must be severely depleted for hypocalcemia to occur.

Dietary sodium needs a brief mention here. Sodium chloride increases urinary calcium excretion (i.e., it contributes to the obligatory loss), and this could theoretically lead to bone loss on a low-calcium diet. This sodium-induced urinary calcium loss can generally be offset by consuming more calcium in the diet.

Calcium Sources

Important sources of calcium are natural foods (principally dairy, a few greens and nuts, and a few crustaceans) and calcium-fortified foods (some cereals, breads, and fruit juices). Dairy products are the richest dietary sources of calcium. In fact, it is difficult to get enough calcium on a dairy-free diet. One serving of dairy has approximately 300 mg of calcium in addition to protein, phosphorus, vitamins, and trace minerals. Even patients with lactose intolerance can "wean" themselves onto dairy foods if done slowly and milk is taken with other foods [5].

Not all food sources of calcium are equally bioavailable. For example, spinach contains 122 mg of calcium per 90 g serving, but very little (about 5%) is absorbed because the oxalate in the spinach interferes with calcium absorption. This can be a source of clinical confusion to patients who are depending on the calcium content of certain foods but are still deficient with respect to calcium stores and bone mineral density.

Calcium supplements may be needed in order to reach the recommended daily intake. Most calcium salts (citrate, carbonate, phosphate) exhibit similar bioavailability [6]. Brand name or chewable products have been shown to be the most reliable. Even relatively less soluble salts, such as carbonate, absorb well if taken with food. All calcium sources should be taken with meals and in small amounts throughout the day to ensure optimal absorption.

Vitamin D

Vitamin D is a second nutrient that is closely linked to bone health. Deficiency of this vitamin is classically associated with unmineralized bone matrix, expressed as rickets in the growing skeleton and osteomalacia in the fully formed skeleton. Vitamin D is not truly a nutrient, at least in humans, because the body makes the vitamin for itself when a precursor in the skin is exposed to ultraviolet-B light. This reaction forms pre-vitamin D, which is then spontaneously converted to vitamin D. At prevalent levels of sun exposure, vitamin D is converted almost entirely to 25-hydroxyvitamin D (25OHD) by the liver. This is the form of vitamin D that correlates best with calcium absorption in adults and is converted by the kidney and other cells to the active form of vitamin D, 1,25-dihydroxyvitamin D ($1,25OH_2D$). Like calcium, $1,25OH_2D$ is physiologically regulated, and serum measurements do not reflect vitamin D status. Although it still remains controversial, vitamin D has been implicated in the prevention of cancer and cardiovascular disease, immune response, and cell cycle regulation [7–10].

Vitamin D is essential for the active absorption of calcium. From multiple calcium absorption studies, it has been established that absorption plateaus at about 32 ng/ml [11]. Population-based studies demonstrate that bone mineral density increases in relation to 25OHD status [12]. Reduction in the risk of fracture has been reported in some clinical trials of vitamin D supplements [13]. The decrease in fractures appears to be the result of at least two mechanisms: first, vitamin D increases calcium absorption, which in turn increases bone mineral density, and second, vitamin D has an effect on muscle strength and balance. Even short-term studies show a reduction in falls [14–16]. Although large bolus doses have been associated with an increase in falls and fractures [17], indicating that large infrequent doses may not be as protective as smaller, more consistent dosing. As with calcium, the

baseline vitamin D status must be taken into account. Greater than adequate vitamin D status (which is thought to be somewhere in the range of 30–50 ng/ml) is not necessarily providing more benefit to bone outcomes.

Vitamin D Requirements

Vitamin D intake recommendations have been a source of considerable controversy in recent years. In 2011, the Food and Nutrition Board (Institute of Medicine) revised their recommendations to 600–800 IU (15–20 mcg) daily [4], but that was challenged by several groups as being too low for optimal health [18–20]. Unlike calcium and other nutrients, vitamin D is made in the skin. The total input is difficult to quantify and is dependent on many environmental factors; these are discussed below. Those of us who live away from the equator, have dark skin, and/or work indoors are at greater risk of deficiency. The simplest way to assess vitamin D status is by checking 25OHD levels. If the level is less than 32 ng/ml, supplementation with an oral vitamin D product is the simplest way for a person to get an adequate amount (see below).

Sources of Vitamin D

Food

Few foods are sources of vitamin D. The best food source is oily fish such as salmon, but there are large differences in vitamin D content between farm-raised and wild salmon. Farm-raised salmon has approximately 188 IU/3.5 oz. serving, whereas wild salmon has much more, approximately 1090 IU/3.5 oz. serving [21]. Milk in the United States and Canada is routinely fortified with small amounts of vitamin D, typically 100 IU per cup. Some cheeses, yogurt, and cereals are fortified with a small amount of the vitamin.

Sunshine

Many variables affect the skin's ability to produce vitamin D, including weather, season, latitude, altitude, pollution, clothing, age, and sunscreen. Skin pigmentation also interferes with vitamin D production as melanin acts as a natural sunscreen.

The season of the year plays a large part in determining the production of vitamin D. Those with light skin require an exposure to summer midday sun of about 15 min daily to allow adequate synthesis of vitamin D. This is with a relatively high proportion of the skin exposed and before sunscreen is applied. It is not necessary to burn or redden the skin. Those with darker skin require at least twice as much time in the sun. In the winter, UVB rays do not penetrate the atmosphere, except close to the equator. During that season, therefore, no vitamin D can be produced, and most patients will need to use supplements.

The light source used in tanning booths may be able to produce UVB rays, and this can therefore be a source of vitamin D. However, tanning booths are not regulated by the FDA, and it is difficult to know how much, if any, UVB rays are produced [22]. Moreover, the light source may also generate UVA rays which can cause skin aging and of course skin cancer; therefore, their use should be discouraged as a vitamin D source.

Supplements

Nutritional supplements for vitamin D come in two forms. Vitamin D_2 is produced by irradiating yeast, while vitamin D_3 is the animal form produced by the skin. Several studies have shown that

vitamin D_3 is between three and nine times more potent at maintaining 25OHD levels [23–25]. The question always arises as to how much to give. Rather than rely on a "one-size-fits-all" recommendation, which does not account for differences in skin pigmentation, sun exposure, age, or weight, the simplest method is to measure the patient's 25OHD level. In calculating supplement dose for a normal-weight person, a good rule of thumb is that 100–150 IU daily will raise 25OHD levels by ~1 ng/ml. In practice, this translates to between 1000 and 2000 IU daily for most patients. For an obese patient, who will have a greater volume to fill, we found the following formula is helpful: additional daily vitamin D3 dose (IU) = [weight (kg) * desired change in 25(OH)D *2.5] – 10 [26]. Occasionally, patients with malabsorption or history of gastrointestinal surgery may require substantially more vitamin D, and in this case the 25OHD level dictates the dose.

These recommendations are based on several clinical studies of different doses of vitamin D and also on clinical experience. This approach treats patients with lower vitamin D levels with higher amounts of vitamin D. Of course, empiric treatment regimens can be used, and again, 1000–2000 IU (25–50 mcg) daily seems to be adequate for many patients and is a good place to start without the risk of toxicity.

Safety

Vitamin D is a fat-soluble vitamin, and there is a valid concern that toxicity may occur at high intakes. Fortunately, there is a wide gap between the amounts of vitamin D that we typically recommend to patients and potentially toxic amounts. A review of toxicity reports and clinical trials found that doses <30,000 IU daily or achieved 25OHD levels <200 ng/ml were not associated with toxicity and concluded that the tolerable upper limit should be 10,000 IU daily [27]. The IOM used a more conservative tolerable upper limit of 4000 IU daily [4]. We find in practice that we occasionally need to give >10,000 IU daily to particular patients who have malabsorption (i.e., occurring after gastric bypass).

Other Vitamins

There are other vitamins besides vitamin D that might contribute to healthy bones. One of these is vitamin K. This vitamin may be best known for its role in blood clotting, but there is new evidence to suggest that vitamin K may play an important role in bone health. Bones contain a protein called osteocalcin, which is used as "glue" to help strengthen bones. Vitamin K is required for the production of osteocalcin, and when vitamin K is low or insufficient, these proteins will not be activated. Some recent studies have shown that vitamin K deficiency is associated with low bone mineral density and an increased risk of fractures.

There are several different types of vitamin K. The vitamin K available from our diet is found mostly in leafy green vegetables, such as spinach, broccoli, and kale (K_1). As a general rule, the darker green the vegetable, the more vitamin K it contains. Vegetable oils can also contain significant amounts of vitamin K. It is also produced by the bacteria that line the GI tract (K_2). Finally, vitamin K is also available in a synthetic form as a supplement. At this time, it is not recommended to take vitamin K supplements to prevent osteoporosis or fractures. Taking a supplement does not always have the same effect as eating whole foods that contain the same nutrient, and because of the role vitamin K plays in blood clotting, getting too much could cause problems in people at risk for blood clots.

Because of vitamin K's effects on clotting, people taking certain anticoagulation medications are often advised to limit their intake of foods high in vitamin K. Patients taking these types of medications should work with their healthcare providers to make sure that their diet contains adequate amounts of nutrients.

Protein

Bone is one of the most protein-dense tissues. When bone is remodeled and new bone is laid down, it requires fresh dietary protein. Dietary protein is known to increase urine calcium excretion, but this effect is offset by higher calcium intakes. Studies of protein intake show that, overall, it is good for bone both as a source of building materials and through effects of insulin-like growth factor. In the Framingham Study, age-related bone loss was inversely related to protein intake [28]. In a calcium intervention trial, only subjects with the highest protein intake and calcium supplementation gained bone [29]. In patients with hip fractures, mortality and recovery are improved if the patients have adequate protein intake (≈1 g protein/kg body weight/day) [30].

The general population of the United States has adequate protein intake, but the population at most risk for fracture are the ones most likely to consume a diet deficient in protein. The recommended dietary allowance (RDA) for protein for adults is 0.8 g per kg body weight per day, although this may not be adequate for a patient with a recent fracture. Animal protein foods include meat, poultry, fish, dairy products, and eggs. Plant foods include beans, nuts, and seeds.

Phosphorus

Bone mineral consists of calcium phosphate. Adequate dietary phosphorus is therefore as important as calcium for building bone. Without it, the patient will develop a form of osteomalacia; they will not mineralize the skeleton. Fortunately, phosphorus is plentiful in many plant and animal tissues, and if one has a diet with adequate protein, it also likely contains adequate phosphorus. Dairy products, meat, and fish are good sources of phosphorus.

Absorption of phosphorus is highly efficient. Net absorption is about 55–80%. Phosphorus is also efficiently retained by the body by reducing urinary phosphorus excretion. However, calcium supplements may interfere with phosphorus by acting as a binder and reducing its absorption from the GI tract. This is a good example of the general rule that food sources of nutrients are superior to a nutrient ingested in isolation. In this case, a serving of dairy food will supply phosphorus in addition to the calcium and protein needed for bone health.

The RDA for phosphorus for adults is 700 mg/day, and most of the US population obtains enough of the mineral from their diet. However, some groups may have an inadequate intake such as one-third of girls between 9 and 18 years old [31]. This group is also likely to have a diet deficient in other nutrients, including calcium and protein. Also of concern are those eating very strict vegetarian diets as these do not contain enough phosphorus in a usable form.

Magnesium

About 50% of the body's magnesium resides in the skeleton. It may serve as a reservoir for maintaining the extracellular magnesium concentration. Unprocessed foods are good sources of magnesium. Rich sources include fresh leafy vegetables, whole grains, and nuts. The body is efficient at absorbing magnesium from the diet, and about 40–60% is absorbed. The kidney is also efficient at retaining magnesium unless the patient has diabetes or alcoholism that leads to urinary magnesium loss. Measuring magnesium status can be difficult clinically because serum measurements correlate poorly with intracellular levels.

Currently, the role of magnesium in maintaining bone density and preventing osteoporosis is unclear. Cross-sectional studies have not revealed any relationship between magnesium intake and bone density. Controlled studies of magnesium supplementation show a possible increase in bone

mineral density. With the paucity of evidence for bone health, we would recommend that patients increase fruit and vegetable intake for general health, but would not make specific recommendations for magnesium supplementation.

Conclusion

In conclusion, building and maintaining bone structure require a symphony of nutrients with food being the ideal source of these nutrients. Individuals with inadequate sources of nutrients will benefit the most from supplementation.

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Suggested Further Readings

International Osteoporosis Foundation: Calcium. https://www.iofbonehealth.org/osteoporosis-musculoskeletal-disorders/osteoporosis/prevention/calcium.
International Osteoporosis Foundation: Nutrition. http://www.iofbonehealth.org/nutrition.
National Institute of Health Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Calcium-HealthProfessional/.
National Osteoporosis Foundation: Calcium and Vitamin D. https://www.nof.org/patients/treatment/calciumvitamin-d/.
National Osteoporosis Foundation: Food and Your Bones. https://www.nof.org/patients/treatment/nutrition/.
Up-To-Date Calcium and Vitamin D for Bone Health. http://www.uptodate.com/contents/calcium-and-vitamin-d-for-bone-health-beyond-the-basics.