20 key nutrients for bone health

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Depending on how we count them, there are at least 20 bone-building nutrients which are essential for optimal bone health — "essential" in that our bodies cannot manufacture them, so we must get them from our food and drink. Let's take a quick look at them, one by one, so you can get a better idea of their roles in bone health and how much of each you should be getting. Remember, none of these nutrients does its work in isolation — you need some of each and every one, so they can all work together to keep your bones standing strong all your life long.

Table of 20 essential bone-building nutrients

Nutrient	Adult RDA or AI*	Common therapeutic range for bone health (daily intake)	Dietary considerations concerning adequacy of average daily intake	Your intake
Key minerals				
Calcium (Ca)	1000–1200 mg	1000–1500 mg	Typical diet is inadequate, averaging 500–850 mg.	
Phosphorus (P)	1250 mg, 9–18 yrs 700 mg, adults	800–1200 mg	Inadequate intake is rare except in elderly and malnourished. Excess intake common with use of processed foods and soft drinks — ~ 1500 mg/day in men and ~1025 mg/day in women.	
Magnesium (Mg)	420 mg, adult males 320 mg, adult females	400–800 mg	Intake generally inadequate among all ages, sexes, and classes except children under the age of 5; 40% of total population and 50% of adolescents consume 66% of RDA; and 56% of all Americans have intakes below Estimated Average Requirement (EAR).	
Fluoride (F)	4.0 mg, adult males 3.0 mg, adult females	Unknown	Intake generally ranges 0.2–3.4 mg. Fluoride overdose has occurred through ingestion of fluoride toothpaste and high-fluoride waters (Brown, 2005).	
Silica (Silicon — Si)	No values set to date	As yet undetermined	Intake significantly higher in men (30–33 mg/day) than in women (~25 mg/day), yet generally suboptimal. Silica is the first element to go in food processing.	
Zinc (Zn)	11 mg, adult males 8 mg, adult females	20–30 mg	Average intake is 46–63% of RDA. Marginal zinc deficiency is common, especially among children.	
Manganese (Mn)	2.3 mg (AI), adult males 1.8 mg (AI), adult females	10–25 mg	Intake generally inadequate, at 1.76 mg adolescent girls; 2.05 mg adult females; and 2.5 mg adult men.	

Copper (Cu)	900 mcg, adults (0.90 mg)	1–3 mg	75% of diets fail to contain RDA. Average daily intake is below the RDA.
Boron (B)	No RDA established	3–5 mg	Common daily intake is only 0.25 mg, to possible optimum of 3.0 mg.
Potassium (K)	4700 mg, adults	4000–6000 mg	Adult intake averages 2300 mg for women and 3100 mg for men.
Strontium	No RDA established	3–30 mg (supplements) up to 680 mg (in medications)	Daily dietary intake thought to vary from 1 mg to more than 10 mg.
Key vitamins			
Vitamin D	400 IU, infancy–59 yr 400 IU, 51–70 yr 600 IU, >70 yr	800–2000 IU and up, as needed	The overwhelming news from numerous experts is that a billion people worldwide are deficient today. Deficiency is especially common among people who are elderly, dark skinned, and those with little UV sunlight exposure. A simple, inexpensive blood test for 25(OH)D is the best way to determine vitamin D status and need.
Vitamin C	90 mg, adult males 75 mg, adult females	Oral 500–3000 mg (and upward to bowel tolerance), as needed.	Average daily intake is about 95 mg for women and 107 mg for men. Based on US survey of nearly 9000 people, intake for 31% of population is below Estimated Average Requirement (EAR).
Vitamin A	2997 IU, adult males 2331 IU, adult females	5000 IU or less	44% of US population has intake below EAR.
Vitamin B6	1.3–1.7 mg, adult males 1.3–1.5 mg, adult females	25–50 mg	Studies indicate widespread inadequate vitamin B6 consumption among all sectors of the population; >50% of population consume <70% RDA.
Folic acid/folate (vitamin B9)	400 mcg, adults (0.4 mg)	800–1000 mcg (0.8–1 mg)	Inadequate intake common among all age groups; although improving with food fortification, 49% of participants in NHANES survey had intakes below estimated average requirement (EAR).
Vitamin B12	2.4 mcg, adults	10–1000 mcg	Up to 40% of US population have marginal B12 status. Older people and vegans are especially at risk.
Vitamins K1 and K2	K1: 120 mcg, adult	K1: 1000 mcg	K1: Averages 45–150 mcg, which is well below the recommended

	males 90 mcg, adult females K2: No recommended intake	K2: 45–180 mcg MK-7 (menaquinone-7)	AI. K2: Average US intake 9–12 mcg (if any)
Other nutrients			
Fats	Should comprise minimum of 7% total calories. General recommendation is not to exceed 30% of caloric intake.	20–30% of total calories is perhaps more ideal.	Average American consumes ~33% of his/her calories in fat. Consumption of essential fatty acids (EFA's), however, is frequently inadequate.
Protein	0.8 g/kg per day, adult males and females 125–lb person = 45 g 175–lb person = 63 g 56 g, adult males 46 g, adult females	1.0–1.5 g/kg	Daily intake commonly exceeds 100 g, but the elderly and some women often have very deficient intake. Higher protein intake should be balanced with higher RDA level potassium intake from food sources.

About Dietary Reference Intakes (DRI),
Adult Recommended Dietary Allowances (RDA),
Adequate Intakes (AI), and
Estimated Average Requirements (EAR)

- The Dietary Reference Intake (DRI) is a system of nutritional guidelines developed by the Institute of Medicine (IOM) of the US National Academy of Sciences. It was first introduced in 1997 to broaden the set of existing Recommended Daily Allowance, which is the system currently still in use in food nutrition labeling. The DRI includes two sets of values that serve as goals for nutrient intake (from the National Academy of Science). These are the RDA and Adequate Intake (AI).
- RDA represents the daily dietary intake of a nutrient regarded to be sufficient for meeting the requirements of nearly all (97–98%) healthy individuals in each age and gender group. The RDA reflects the average daily amount of a nutrient considered adequate to meet the needs of most healthy people. If there is insufficient evidence to determine an RDA, an AI is set.

Adult RDA figures come from: National Academy of Sciences, Institute of Medicine, and the Food and Nutrition board. Through the United States Department of Agriculture Food and Nutrition Information Center website. Dietary Reference Intakes for individuals (PDF): http://www.iom.edu/Object.File/Master/21/372/0.pdf.

- AI values are more tentative than RDA, but both may be used as goals for nutrient intake.

- In addition to the values that serve as goals for nutrient intakes, the DRI includes a set of values called Tolerable Upper Intake Levels (UL). The UL represent the maximum amount of a nutrient that appears safe for most healthy people to consume on a regular basis.
- The Estimated Average Requirement (ERA) calculations are the average daily nutrient intake level estimated to meet the requirement of half of the healthy individuals in a particular life stage and gender group. They are established by the Institute of Medicine (IoM).

Keep in mind that these are values that are meant to cover adequacy for most folks, not for optimizing health! The common therapeutic dose for bone health may be significantly higher in "special need" cases.

Key minerals for bone health

Calcium

Of all the minerals in the body, there is more calcium than any other. It makes up somewhere around 2% of our total adult body weight, stored mostly in our bones and teeth. Bone is made up of a crystalline mineral compound embedded within a living protein matrix. This crystalline mineral compound, called hydroxyapatite, is formed principally from calcium and phosphorus. It is essential for healthy bone development and bone maintenance, and gives our bones both strength and rigidity.

Here in the United States, about 80% of our calcium comes from dairy sources. But research indicates that dietary calcium from sources such as vegetables, fruits, or the small bones of fish such as canned salmon or anchovies, may be much more readily absorbed than calcium from dairy foods. While most Americans think they need to drink milk to get enough calcium, bok choy, a variety of Chinese cabbage, is one of the best calcium bargains around as far as absorbability per unit of energy — providing around 1800 mg calcium per 100 calories! Another good source is bones themselves: since the invention of fire, people have been boiling up bones for the rich nutrients they contain. (Homemade broth is not only curative for the common cold, it's prophylactic for bone health!)

As for calcium supplements, it's true that not all are created equally. We hear a lot about the different forms of supplemental calcium and which ones are best. But the biggest story with calcium is not so much about which form to use as it is about calcium absorption — which itself is contingent on a complex interplay of hormones and other factors, chief of which is vitamin D.

While it's interesting that calcium comes in all these various forms, without adequate vitamin D on board (vitamin D sufficiency is commonly defined as a 25(OH)D blood level of at least 32–34 ng/mL), all the calcium in the world will result in little material gain for our bones. In fact, noted calcium researcher Dr. Robert Heaney has found that different individuals can have a nearly threefold difference in their calcium absorption rates — a phenomenon for which we currently have only limited explanation. Aside from how replete our vitamin D stores are, how well we absorb calcium has much to do with the health of our digestive system.

As to which forms optimize both absorption and bioavailability, alkalizing calcium salts are the best calcium compounds known to date. These forms include calcium citrate, calcium citrate–malate, calcium ascorbate, and calcium carbonate. Calcium citrate and its relative, calcium citrate–malate (CCM), are sources that do not require hydrochloric acid (HCl) from the stomach for absorption, so the calcium in them is very bioavailable to

the body and a good choice for people with low stomach acid. Calcium in the form of calcium citrate also appears to play a protective role against the formation of kidney stones, and does not appear to interfere with iron absorption from food. Calcium carbonate is often found not to be as well absorbed as citrate, but does alkalize well in the body if taken with food. (Calcium absorption from all forms is generally better when taken with a meal.)

Regardless of what form your calcium supplementation takes, it should always be balanced with magnesium supplementation. Some bone specialists favor magnesium-centered formulations with equal or slightly more magnesium than calcium. As a rule of thumb, I recommend at least half as much magnesium as calcium (a ratio of 1 part magnesium to 2 parts calcium), and in most cases I prefer nearly as much magnesium as calcium. People with osteoarthritis, in particular, want to use equal amounts of magnesium and calcium (1:1).

Many US experts now suggest that the ideal daily calcium intake from all sources, including food and supplements, would be in the range of 1000–1200 mg.

Phosphorus

Phosphorus is the second most abundant mineral in the body, making up a full 25% of all the mineral material in the body. Nearly all the biochemical reactions taking place in the body involve phosphorus, including regulation of proteins and energy production through the process known as phosphorylation; hormone signaling, cell growth and repair; heart contraction; nerve and muscle activity; calcium, glucose, fat and starch metabolism; and pH buffering to maintain acid–alkaline balance in the body. Also of special interest to us is the fact that phosphorus combines with calcium to form a mineral crystal that gives strength and structure to our bones and teeth. Of all the phosphorus in the body, 80% of it is found in the teeth and bones in the form of crystalline bone, hydroxyapatite.

But while phosphorus is essential for bone health, too much of it is not a good thing. It must work in delicate balance with calcium in our bones and blood. The average American diet contains much more phosphorus than calcium (see table). Large amounts are found in meat, soft drinks, and processed foods. Instead of the more ideal ratio of nearly one part calcium to one part phosphorus, many Americans consume twice as much, or more phosphorus than calcium. This high phosphorus-to-calcium ratio can be detrimental to our bones.

Magnesium

Overall, magnesium assures the strength and firmness of bones and makes teeth harder. Since magnesium participates in an astonishing array of biochemical reactions, it’s no surprise that it’s essential for healthy bones and teeth. Most notably, adequate magnesium is essential for absorption and metabolism of calcium. It also has a role to play, together with the thyroid and parathyroid glands, in supporting bone health: stimulating the thyroid’s production of calcitonin, which acts as a bone-preserving hormone, and regulating parathyroid hormone, which acts as a bone breakdown force.

Magnesium is an essential cofactor in 80% of all cellular enzymes. It is necessary for the conversion of vitamin D into its active form, and a deficiency of magnesium can lead to a syndrome known as vitamin D resistance. The enzyme required for forming new calcium crystals, alkaline phosphatase, also requires magnesium for activation, and if levels are low, abnormal bone crystal formation can result. Even mild magnesium deficiency is reported to be a leading risk factor for osteoporosis.

As with calcium, the majority of the body's reserves of magnesium are held in the bone (60%), and the bones act as a storage reservoir, transferring magnesium to the blood in times of need. Adequate daily intake of magnesium is important throughout life to keep magnesium stored in the bones from being lost. Low magnesium intake, as well as low blood and bone magnesium levels, has been widely associated with osteoporosis in women.

It's often overlooked that magnesium and calcium function together, so deficiency of one markedly affects the metabolism of the other. In fact, increasing calcium supplementation without increasing magnesium supplementation can actually increase magnesium loss. Similarly, the use of calcium supplements in the face of a magnesium deficiency can lead to calcium deposition in the soft tissues, such as the joints, where it can promote arthritis, or in the kidney, contributing to kidney stones.

There has been conflicting opinion about the need for concern about the adequacy of our magnesium intake. Despite its recognized importance, most Americans consume less than the Estimated Average Requirement (EAR) for magnesium. In fact, in 2001, 56% of the US population did not consume the Estimated Average Requirement for this mineral.

Fluoride

Through the action of fluoride, bones and teeth become harder, more uniform, and display greater resistance to decay and demineralization. Fluoride is present in small amounts in many foods, and many if not most public water supplies today in the US contain fluoride. There is, however, a great controversy surrounding the use of fluoridated water. One school of thought is that we've been brainwashed into thinking we need to fluoridate our drinking water — it's certainly true that there are many societies that do not engage in this practice, where the people enjoy gorgeous teeth and bones. Excessive fluoride intake, whether from fluoridated water or medication, can weaken our bones. Some studies have suggested that high fluoride intake, including artificial fluoridation in low amounts, can actually increase the risk of osteoporotic fractures. But the data have been mixed, and the controversy regarding fluoride's linkage to hip fractures and bone cancer continues.

Silica

Silica is the most abundant mineral on earth. We don't fully understand its full range of functions in the human body, but we do know that silica content is high in the strongest tissues of the body, including the arteries, tendons, ligaments, connective tissue, collagen, skin, nails, hair, and teeth.

Although no RDA has been established yet for silica, this mineral clearly makes a direct contribution to bone health. Bone collagen is reported to increase with silica supplementation, and the mineral appears to strengthen the connective tissue matrix by cross-linking collagen strands. Dietary silicon appears to increase the rate of mineralization, particularly when calcium intake is low. A concentration of silica is found in the areas of active bone mineralization, and silica combines with calcium in the bone-building cell. Overall, silica plays an important role in initiating the calcification process, thus helping us to maintain strong, flexible bones.

Populations with higher intakes of plant-based foods have higher silica intakes than do Western populations; and not surprisingly, the incidence of hip fractures in these communities is also lower. Silica is plentiful in many fibrous foods, but as nutrition educator Betty Kamen reports, the fiber in foods (and its silica content) is the first to go in the processing of foods. Since up to 80% of the food we consume today is processed

— compared with a mere 10% at the turn of the century — silica consumption has dramatically declined in just a few generations. Of interest is that the major source of silica in American men's diets was found to be beer and bananas, while in women it was bananas and string beans!

Zinc

In bone metabolism, zinc is needed to produce the matrix of collagen protein threads upon which the bone-forming calcium–phosphorus compound is deposited. It's also necessary for the production of enzymes that degrade and recycle worn-out bits of bone protein. Proper calcium absorption also depends on zinc, and a deficiency prevents full absorption of calcium. It's essential for bone healing, and increased amounts are found at the sites of bone repair. Low levels in the body have been closely linked with osteoporosis.

It's unfortunate that in the face of declining intake and growing deficiencies of zinc in the American diet, authorities have seen fit to lower zinc requirements. Mild — but still clinically significant — zinc deficiency is widespread and far-reaching in its effects. The 2–3 grams of zinc found in the body act as a co-factor in over 200 enzymatic reactions that are instrumental in maintaining not just the health of our bones, but for optimal system-wide functioning.

Manganese

Like zinc and copper, manganese is a trace element that can profoundly affect bone health. Yet for a long time it was one of the most overlooked nutrients, and to date no RDA for manganese has been established.

One reason cited for this lack of an RDA in the past was that scientists weren't really sure what people's typical manganese intakes were. It appears manganese intake can vary widely depending on basic food choices. For example, we now know that intake of manganese is greatly reduced when whole grains are replaced in the diet with foods made from refined flour. This gives us pause because grain products constitute nearly 40% of our daily manganese intake. Beverages (particularly tea) contribute about 20%, and vegetables less than 20%. Other dietary patterns can inhibit the absorption of manganese, such as getting too much calcium, phosphorus, iron, or zinc.

In recent decades research has uncovered the special role manganese plays as a co-factor in the formation of bone cartilage and bone collagen, as well as in bone mineralization. Osteoporotic changes in bone can be brought about by manganese deficiency, which appears to increase bone breakdown while decreasing new bone mineralization. Blood levels of manganese of severely osteoporotic women were found in a Belgian study to be just one-fourth those of non-osteoporotic women their same age. What's more, of the 25 variables studied, only manganese was significantly different between the two groups. Fortunately, manganese deficiency is relatively easy to address and dietary sources are extremely safe.

Copper

Like manganese, copper is an essential trace mineral that has only recently been found to play an important role in bone health maintenance. This role is still not fully understood, but we do know that by virtue of a copper-containing enzyme called lysyl oxidase, copper aids in the formation of collagen for bone and connective tissue and contributes to the mechanical strength of bone collagen fibrils — the long thin strands of proteins that cross-link to one another in the spaces around cells. Copper also helps inhibit bone resorption through a copper- and zinc-containing antioxidant called

superoxide dismutase. This antioxidant neutralizes superoxide radicals produced by the bone-breakdown cells called osteoclasts during bone resorption.

Again, as with manganese, inadequate copper levels have been associated with the development of osteoporosis. And as with so many other minerals, copper excretion from the body is increased on a diet high in sugar, other sweeteners like fructose, and refined flour. Some researchers have suggested that even lactose (milk sugar) could interfere with copper metabolism, making high dairy intake less than ideal for copper utilization. With our penchant for sugar, refined flour, and dairy, it's not surprising that copper is among the minerals most often deficient in the American diet.

Boron

Boron is another one of the elements in our list that has been discovered only in recent years to be essential to bone health. The body requires boron for proper metabolism and utilization of various bone-building factors, including calcium, magnesium, vitamin D, estrogen, and perhaps testosterone. Though results have been somewhat mixed and the mechanisms have yet to become clear, studies overall show that boron has a mineral-conserving and estrogen-enhancing effect, especially among women with low magnesium intake. Lead researchers now consider boron important in the utilization and metabolism of calcium and vitamin D, as well as important for overall hormonal balance.

Though RDA's for boron have yet to be established, we know that our ancestors consumed much more of this nutrient than most of us do today. Excessive boron in the supplemental form can be toxic, but there's no need to restrict boron from our food sources. It's easy enough to consume as much as 10 mg per day with a diet plentiful in fruits, veggies, and nuts, which could account for a lower osteoporosis rate among vegetarians. In fact, there are places in the world where people consume as much as four times this amount without adverse effects.

Potassium

I like to call potassium the "hidden bone guardian," as the role it plays along with sodium in maintaining critical fluid balance is widely known, but potassium's service to bone health is less well appreciated. This role relates mainly to the ability of certain alkalinizing potassium compounds to neutralize the bone-depleting acids that are produced during everyday normal metabolic processes. In maintaining the acid–alkaline balance in our bodies, potassium prevents too much calcium from being excreted in the urine.

Diets low in potassium increase net urinary calcium loss, whereas diets high in potassium reduce it. In fact, dietary potassium can offset the excretion of absorbed calcium to such an extent that eating one medium baked potato or one large banana can conserve about 60 mg of calcium! Supplemental potassium in the form of potassium salts such as potassium bicarbonate and potassium citrate can also help decrease urinary loss of calcium.

The transition in our diet in recent generations to one that is lower in fruits, vegetables, and legumes has resulted in significantly decreased potassium intake. Yet we know that higher potassium intake, particularly in the form of fruits and vegetables, is directly associated with overall higher bone mineral density and less bone loss — all the more motivation for us to renew our "5–10-a-day" pledge!

Strontium

Strontium is a mineral that naturally exists and is present in small amounts in our food and water. Strontium has a high affinity for bone and is thought to play a critical role in

bone health. It tends to migrate to the sites where active remodeling is taking place and promotes mineralization of the bones and teeth. There are about 320 mg of strontium in the body, with 99% of this located in the bones and teeth. The typical daily diet is thought to contain from as little as 1 mg to more than 10 mg strontium. This stable mineral form of strontium found in food and water should not be confused with the radioactive form of strontium that is produced by nuclear reactors or by explosion of nuclear weapons.

In the periodic table you will find strontium below calcium, and it belongs to the same chemical family as calcium and magnesium. In fact, because of its similarities, strontium is capable of replacing a small proportion of calcium in the calcified crystals of bone and teeth. As it appears, strontium adds strength to these tissues, making them more resistant to breakdown. Strontium also appears to draw extra calcium into the bone.

Dietary strontium is consumed in very small, milligram quantities and is considered a natural and beneficial bone nutrient. It is found in most plant foods, dairy foods, Brazil nuts, and again, naturally in drinking water. Very high-dose (several hundred-milligram dose) synthetic strontium ranelate (Protelos) has been developed in Europe as a prescription osteoporosis medication and is used for the purpose of both halting bone breakdown and enhancing new bone formation.

Key vitamins for bone health

Vitamin D

This amazing vitamin serves as the body's great regulator of calcium and phosphorus metabolism in three major ways:

- Vitamin D mobilizes calcium and phosphorus for release from bone in the presence of parathyroid hormone.
- Vitamin D promotes intestinal absorption of calcium and phosphate.
- Vitamin D increases kidney absorption of calcium and phosphorus and carries them into the blood.

Adequate vitamin D nutrition is crucial at every stage of our lives, from childhood to old age. But for decades both the prevalence and implications of vitamin D deficiency have been grossly underestimated. A simple test can quickly tell you and your healthcare provider whether you have sufficient stores of vitamin D — don't hesitate to ask for this important test — your lifelong health depends on it!

Simply with respect to bone health, the body cannot properly absorb calcium without vitamin D, and the bones and teeth become soft and poorly mineralized. In young children, a deficiency causes poor mineralization of the collagen matrix, which results in growth retardation and the bone deformity condition known as rickets. In adults, vitamin D deficiency results in a type of bone-softening adult rickets, known as osteomalacia. Inadequate levels of vitamin D also directly affect bone as it causes a condition known as secondary hyperparathyroidism, which stimulates a loss of matrix and minerals, in turn increasing the risk of osteoporosis and fractures.

Recently there has been a veritable explosion of research on vitamin D and its effects throughout the body. Inadequate levels of vitamin D have now been associated with numerous types of cancer, cardiovascular disease, hypertension, stroke, diabetes, multiple sclerosis, rheumatoid arthritis, periodontal disease, macular degeneration, mental illness, propensity to fall, and chronic pain.

The newly identified link between low vitamin D status and cancer has drawn particular attention. A recent study, for example, showed that women with adequate blood levels of vitamin D at diagnosis had a much better outcome and much less metastases of their breast cancer than did those who were vitamin D-deficient at diagnosis.

Also, for years it has been known that osteopenia, osteoporosis, and needless fractures are linked with low levels of vitamin D. Nearly two decades ago one prominent osteoporosis researcher concluded that, in general, the more adequate the state of vitamin D nutrition, the less bone loss among the elderly. We now know that women of all ages can actually halt bone loss, and even increase their bone density over the course of the year by consuming adequate calcium and getting adequate amounts of vitamin D — the “sunshine vitamin.” This is especially true during the dark days of winter.

Most importantly, adequate-dose vitamin D is now proven to reduce fractures significantly. Recently, in fact, three major vitamin D researchers estimated that 50–60% of all osteoporotic fractures are due to insufficient vitamin D. And indeed, as documented in a recent publication by the Better Bones Center, various clinical trials support this amazing fracture-reduction capacity of adequate-dose vitamin D.

Although we refer to vitamin D as a vitamin, it is really a pre-hormone which is transformed into a hormone in the body. While we consume small amounts of vitamin D in our diet, most of our vitamin D supply is produced by our bodies upon exposure to sunlight. Our wondrous capacity to produce vitamin D internally appears to decrease with age, however, and elderly people in even the world’s sunniest places are especially prone to low levels of vitamin D. Another fascinating thing about vitamin D is that it directly nourishes muscles. Supplemental vitamin D has now been repeatedly shown to help improve muscle mass and strength and thus help in the prevention of falls. Several studies show a rapid reduction in falls among the elderly with administration of even 800 IU vitamin D. Two recent clinical trials, for example, show a 49% and 72% reduction in falls with 800 IU supplemental vitamin D. If for only this reason alone it is vital that older people obtain higher amounts of vitamin D through their food or supplementation. But again, vitamin D’s effects are far-reaching throughout the body tissues throughout our lives.

Vitamin D is a very complex substance, with many varied forms and myriad biological functions, many of which we have yet to explore and describe. Regarding its pivotal role in mineral metabolism, it’s important to understand that as a hormone, vitamin D exists in both more active and less active states. It is converted to more active states within the body on an as-needed basis. The most active metabolite of vitamin D, known as 1,25-dihydroxyvitamin D, or calcitriol, is produced by our kidneys and in other tissues from less active precursors. It is this active vitamin D hormone that mediates the many biological effects of vitamin D, including calcium absorption. For example, in the absence of activated calcitriol, less than 10% of our dietary calcium may be absorbed! Our ability to absorb calcium via the intestines is, in fact, directly related to our blood levels of this active form of vitamin D. The interesting thing is, as calcium expert Dr. Robert Heaney has demonstrated, intestinal calcium absorption was 65% higher when blood levels of vitamin D averaged 34 ng/mL — we now know this level approaches only the barest minimum needed to ensure system-wide health.

It’s also of note that at extremely high levels, supplemental vitamin D can have toxic effects. For most people, however, this is strictly a theoretical concern, and evidence of toxicity in adults consuming more than 10,000 IU/day is absent in the literature. Nevertheless, it is this theoretical risk that has made so many so leery of vitamin D

supplementation for so long. Even though vitamin D deficiency is common and vitamin D toxicity is rare, it is important to get professional guidance and testing before supplementing at levels greater than 2000 IU per day as this is the current (albeit outdated) “safe upper limit” set by US Food and Nutrition Board. Today we know precisely what levels in the blood are needed for optimal bone health: a minimum of 34 ng/mL, and more ideally, at least 50–60 ng/mL. In reality, many people will need more than 2000 IU vitamin D to achieve this minimum adequate blood level and thus, at Women to Women, we recommend everyone have their vitamin D level tested using the 25(OH)D blood test. Testing is easy, and one of the most powerful tools there is to work with to achieve bone health. Luckily, we need not worry about getting too much vitamin D from our body’s own internal production, since our body simply stops producing vitamin D when levels are adequate.

So as you can see, the last few years have seen an explosion of research on vitamin D. Hundreds of studies link low vitamin D levels to an array of diseases ranging from osteoporosis, auto-immune disease, and cardiovascular disease to diabetes, depression, and cancer. For a comprehensive overview of this exciting new research, you may also wish to visit the Vitamin D Council website, a nonprofit organization founded and directed by Dr. John Cannell:

Vitamin C

Vitamin C is involved in a great variety of complex and interrelated metabolic processes. Here are three ways in which it is essential for healthy bones.

- Vitamin C assists in the formation of collagen. As described in our article on the nature of healthy bones, bone mineral is laid down over a protein matrix called collagen. Collagen is abundant in the connective tissue of cartilage and bone — in fact, it makes up about 30% of our bones, serving as a support structure for mineral deposits and giving bone its resilience.
- In addition to its role in collagen formation, vitamin C appears to stimulate the cells that build bone, enhance calcium absorption, and enhance vitamin D’s effect on bone metabolism.
- A third role for vitamin C and bones is in the synthesis and optimal functioning of adrenal steroid hormones, which play a vital role in bone health — especially during perimenopause and menopause, when ovarian production of these hormones slows.

Even though the RDA’s for vitamin C are a very minimal 90 mg for men and 75 mg for women, great numbers of Americans do not even consume this amount! Many well-qualified scientists, including the late Nobel laureate, Linus Pauling, believe recommended levels are extremely low, and that our health would be greatly served on many levels by a much higher intake per day. At the Better Bones Center, patients are encouraged to strive for an intake of 2000–3000 mg per day to recover and preserve bone health, and more as individual need is determined.

Vitamin A

Vitamin A helps in the development of osteoblasts, the bone-building cells that lay down new bone. A deficiency in vitamin A also limits calcium absorption and metabolism, which results in poor bone growth.

There is some controversy, however, as to whether high vitamin A intakes are actually helpful or more of a hindrance in bone health. Some studies suggest high vitamin A can be bone-damaging, but it’s not at all clear if we understand what’s going on. The jury’s

still out on whether vitamin A might really increase risk of osteoporosis and bone fracture, but in the meantime, we recommend limiting supplemental vitamin A intake to 5000 IU per day.

There are essentially three forms of vitamin A:

- Carotenoids — a large class of natural fat-soluble pigments found principally in plants, including the xanthophylls and carotenes. Some 600+ carotenoids have been identified to date.
- Beta carotene — also referred to as “provitamin A,” beta-carotene is one of the carotenes, a subcategory of the carotenoids. It is the plant precursor source of retinol, from which we make the majority of our vitamin A in the body.
- Retinols — also referred to as “preformed vitamin A,” retinol is the most active form in the body and found mostly in animal sources of food.

Remember, most of the vitamin A in our diets comes from plants in the form of beta–carotene, which is a water-soluble precursor of vitamin A. Retinol, the active form of vitamin A, is found in some animal tissues such as liver, for example, which makes liver a good source of vitamin A. Beta–carotene is converted in the liver to active vitamin A. But because beta–carotene is water-soluble, it’s a totally different story from retinol, in that high intake does not result in excessively high vitamin A levels and is in no way a concern for bone health.

Vitamin B6 (pyroxidine)

Vitamin B6 is another nutrient that plays an important but indirect role in bone metabolism. Here are a few aspects of the work it does for us:

- B6 is necessary for hydrochloric acid (HCl) production by the stomach, and HCl in turn is necessary for calcium absorption.
- B6 is necessary for adrenal functioning. In turn, several dozen hormones are produced by the adrenal glands, some of which aid in maintaining proper mineral balance within the body.
- B6 is also a necessary co-factor in the enzymatic cross-linking of collagen strands, which increase the strength of connective tissue.
- B6 is a factor in the breakdown of homocysteine, which tends to increase in postmenopausal women. Homocysteine is a metabolite of the amino acid methionine, which interferes with collagen cross-linking and leads to defective bone matrix and osteoporosis. It also contributes to the development of heart disease. B6, along with folic acid, helps prevent build-up of homocysteine in the body.
- All in all, more than 50 enzyme systems are directly dependent on vitamin B6, and many others function suboptimally without a sufficient amount of this nutrient.

Studies indicate that inadequate vitamin B6 intake is widespread among all population groups. In one study, all of the 21 “normal American students” studied over a two–week period were found to be functionally deficient in B6.

One of the factors contributing to this problem is the relative instability of vitamin B6, which is destroyed by light and heat. As a result, much of it is lost in food processing, storage, and preparation. In addition, animal protein creates an increased demand for

B6, as do other common B6 antagonists such as yellow dye #5 (food coloring), oral contraceptives, and certain other drugs and alcohol.

Folic acid and folate — forms of the water-soluble vitamin B9

Folic acid is another one of the B vitamins, referred to sometimes as folate (its related anion form), or simply as vitamin B9. The most notable role folate and folic acid play in bone health is in the detoxification of homocysteine, an amino acid linked with inflammation and increased fractures. Anywhere from 5–50% of any given population (varying by geographic region and ethnicity) may have genetic variants that impact their ability to optimally metabolize folate, and thus to prevent homocysteine build-up, detoxify adequately, and keep inflammation at bay.

Homocysteine is a compound produced as a by-product of the metabolism of the amino acid methionine. Normally, homocysteine gets recycled as another substance or eliminated, but excess blood levels can accumulate as a result of genetic or nutritional factors. Excess homocysteine promotes both osteoporosis and atherosclerosis. The proper processing of homocysteine requires folic acid. Researchers suggest that around the time of menopause, women experience a reduced capacity to process homocysteine appropriately. It is not known whether this is a universal trait or one found only in more developed countries. Supplementing with folic acid has been found to improve this homocysteine processing problem.

Deficiency of folic acid is an extremely common problem in many parts of the world where diets of refined foods predominate. The average US intake is only about half the RDA. Women taking oral contraceptives or estrogen replacement, as well as users of alcohol and long-term users of anticonvulsant medications, are at special risk for drug-induced folic acid deficiency.

Vitamin B12 (cobalamin)

Because of their role in the detoxification of homocysteine, vitamins B6, B12, and folic acid have all been recently added to our list of important bone-protecting nutrients. Osteoblasts, the body's bone-building cells, require an adequate supply of B12, or their ability to function properly will be compromised. Vitamin B12 deficiency anemia has been associated with osteoporosis, and having low serum levels of vitamin B12 has also been associated recently with odds of frailty in older women.

Following careful analysis of the Framingham Offspring Study in 2000, Tufts nutritional epidemiologist Katherine Tucker concluded that B12 deficiency may be more widespread than previously thought, with nearly 40% of the US population "flirting" with marginal B12 status, according to the USDA website.

Vitamin B12 is not found in plants, but is abundant in animal protein. Yet vitamin B12 deficiency in the US may be largely linked not so much to inadequate meat, poultry and fish intake — the foods that supply the majority of dietary B12 — but to problems with intestinal absorption. Of interest is that researchers have found intestinal malabsorption to be a problem among the young and the old alike. The problem may lie with inadequate stomach acid, which is required to cleave the vitamin from the animal proteins to which it is tightly bound in food sources. In older folks, the problems with B12 absorption could be due to a loss of active acid-secreting cells in the stomach as we age. But in younger adults, Tucker speculates that the problem could be resulting from the overuse of antacid tablets.

B12 is also one of the few vitamins biosynthesized by the "friendly" flora in our intestines. Though production in the human intestines is not believed to occur to any great degree,

there is still a lot for us to learn about both B12 synthesis and absorption processes, and it is safe to say that maintaining healthy gut flora is one way to encourage adequate vitamin B12 status as well as promote good bone health. After all, the B12 we get from animal sources originally derives from bacterial production, for instance in the rumen of cows.

Vitamins K1 and K2

While vitamin K is best known for its role in blood clotting, this nutrient also plays an important part in the maintenance of healthy bones. Noted nutrition authority Dr. Alan Gaby has suggested that vitamin K is as important to bone as calcium. So let's follow Dr. Gaby's lead and delve a little deeper into its role in bone health.

Vitamin K is required for the synthesis of osteocalcin, the bone protein matrix upon which calcium crystallizes. Osteocalcin provides the structure and order to bone tissue; without it bone would be fragile and easily broken. Vitamin K also aids in the binding of calcium to the bone matrix — in essence, it serves as the "glue" that binds calcium onto the skeleton.

Just as vitamin K is central to bone formation, it also appears to play an important role in fracture healing. Vitamin K levels fall during recovery from fracture, and it appears that this nutrient is actually drawn from the rest of the body to the site of fracture.

Vitamin K is not a single nutrient, but the name given to a group of vitamins of similar composition. The two main groups that occur naturally are phylloquinone, or K1, which is found in plant-based foods, particularly green leafy vegetables; and the menaquinones, or K2, which are produced by bacteria in fermented foods and to some minor extent in our intestinal tracts. In combination with vitamin D and calcium, both vitamins K1 and K2 increase bone quality. But vitamin K2 is more bioavailable, longer lasting, and provides for greater increase in bone strength.

The more we learn about this vitamin, the more we see it takes various forms and roles in the body. To date most of the research has been done on K1. But a new wave of research is now focusing on K2 — in particular the subset of K2 known as menaquinone–7, or MK–7. This research documents the superior ability of MK-7 over K1 to enhance both bone and heart health. Getting enough of the K2 forms of this vitamin has been found to be especially important for healthy bones in patients being treated with oral anticoagulants, such as warfarin (Coumadin).

Aside from getting K through dietary sources, vitamin K can also be produced in the body by certain beneficial intestinal bacteria. By compromising this process, long-term use of antibiotics can lead to vitamin K deficiency. Aside from oral antibiotic and anticoagulant use, culprits in vitamin K inadequacy include the freezing of foods, mineral oil laxatives, rancid and hydrogenated fats, radiation, impaired fat absorption, sulfa drugs, and certain liver diseases.

Other key nutrients in bone health

Essential fatty acids (EFA's)

Conventional wisdom tells us we should cut the fat in our diet, and indeed, too much of the wrong kinds of fat can be detrimental to bone health by decreasing calcium absorption. On average, we Americans consume more than one-third of our calories as fat.

But what we are just beginning to appreciate is that our bodies require certain fats, just as they require certain vitamins and minerals, proteins, fiber, and water. These fats are called essential fatty acids because they are not produced by the body and must be

consumed in the diet or by supplementation. These fatty acids are essential for nerve functioning, hormone production, for the maintenance and functioning of the brain, and for everyday energy production.

Fatty acids also play multiple roles in bone structure, function, and development. Fats are required for proper calcium metabolism, and they are essential components of all membranes, including those of cartilage and bone.

As explained by essential fatty acid researcher Dr. David Horrobin, EFA's increase calcium absorption from the gut, in part by enhancing the effects of vitamin D. They also regulate and reduce urinary excretion of calcium, possibly by reducing production of pro-inflammatory molecules called prostaglandins. In fact, the role omega-3 fatty acids play in countering inflammation is arguably their most bone-critical mission.

EFA's have also been found to increase calcium deposition in bone, which is not surprising since bone calcification must take place in the presence of a type of fat known as a phospholipid. Finally, essential fatty acids appear to improve bone strength, possibly by fomenting collagen synthesis.

Protein

The situation with protein is somewhat similar to that with fat. While some protein is essential, too much is detrimental. Protein is needed for intestinal absorption of calcium, and protein is a major building block for bone. By weight, roughly one-third to one-half of our bone is living organic protein matrix! Protein malnutrition debilitates bone, and can be a significant problem among the elderly in Western countries.

Yet over-consumption of dietary protein (think Atkins diet) — again, if not adequately balanced with alkalizing compounds of minerals like calcium, magnesium, potassium — can likewise lead to bone loss. In this case the loss results from an increased acid load which our bodies must buffer daily by drawing calcium and other alkalizing mineral compounds from the bones.

While adequate protein intake is certainly necessary, the average person in the US consumes far too much protein in the form of meat and dairy products. Not that either of these are bad — we just need to remember to balance them with plenty of alkalizing fruits and vegetables, including some high-carb but nutrient-dense veggies like sweet potatoes and carrots. This excess animal protein intake leads to a state known as chronic low-grade metabolic acidosis (CLGMA), which actually washes calcium out of the body.

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