Better Bones The way *nature* intended

20 key nutrients for bone health — *an overview*

by Dr. Susan E. Brown, PhD

Depending on how we count them, there are at least 20 bone-building nutrients that are essential for optimal bone health — "essential" in that our bodies cannot manufacture them on their own, 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 role in bone health and how much you should be getting.

Remember, none of these nutrients do their 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. Taking a top-grade multivitamin–mineral complex and essential fatty acids will ensure that your cells have adequate levels of these nutrients ready at hand from minute to minute, day after day, to prevent bone loss leading to osteoporosis, other degenerative diseases, and accelerated aging.

(Click through on individual nutrients to learn more...)

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)	1000–1300 mg	1000–1500 mg	Typical diet is inadequate, averaging 500–850 mg[1].	
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.	

[1] US DHHS. 2004. Bone health and osteoporosis: A report of the Surgeon General. Chapter 1: A public health approach to promote bone health. URL: http://www.surgeongeneral.gov/library/bonehealth/chapter_1.html (accessed 05.28.2008).
Wright, J., et al. 2003. Dietary intakes of ten key nutrients for public health, United States: 1999–2000. *Adv. Data*, (334), 1–4. URL (PDF): http://www.cdc.gov/nchs/data/ad/ad334.pdf (accessed 05.28.2008).
Morgan, K., et al. 1985. Magnesium and calcium dietary intakes of the US population. *J. Am. Coll. Nutr., 4* (2), 195–206. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/4019942 (accessed 05.28.2008).

Nutrient	Adult RDA or AI	Common therapeutic range for bone health (daily intake)	Dietary considerations concerning adequacy of average daily intake	Your intake
Chromium (Cr)	30–35 mcg, adult males 20–25 mcg, adult females	200–1000 mcg	Common intake in the US is 50 mcg or lower[2]	
Silica (Si)	No values set to date	5–20 mg	Intake significantly higher in men (30–33 mg/day) than in women (~25 mg/day),[3] 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 (Pennington, et al., 1986). Marginal zinc deficiency is common, especially among children (Brown, 2005).	
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.[4]	
Copper (Cu)	900 mcg adults (0.90 mg)	1–3 mg	75% of diets fail to contain RDA.[5] Average daily intake is below the RDA (Brown, 2005).	
Boron (B)	No RDA established	3–5 mg	Common daily intake is only 0.25 mg,[6] 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.[7]	

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[2] Kumpulainen, J. 1992. Chromium content of foods and diets. *Biol. Trace Elem. Res., 32* (1–3), 9–18. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/1375091 (accessed 10.19.2009).

[3] Jugdaohsingh, R., et al. 2002. Dietary silicon and absorption. *Am. J. Clin. Nutr., 75* (5), 887–893. URL: http://www.ajcn.org/cgi/content/full/75/5/887 (accessed 05.28.2008).

[4] Freeland–Graves, J., et al. 1988. Metabolic balance of manganese in young men consuming diets containing five levels of dietary manganese. *J Nutr., 118* (6), 764–773. URL: http://jn.nutrition.org/cgi/reprint/118/6/764 (accessed 05.28.2008).

[5] Pennington, J., et al. 1986. Mineral content of foods and total diets: the Selected Minerals in Foods Survey, 1982 to 1984. *J. Am. Diet. Assoc., 86* (7), 876–891. URL: http://www.ncbi.nlm.nih.gov/pubmed/3722652 (accessed 05.28.2008).
Klevay, L. 1979. Evidence of dietary copper and zinc deficiencies. *JAMA, 241*, 1917–1918. URL (abstract): (accessed 05.13.2008).

[6] Nielsen, F., et al. 1987. Effect of dietary boron on mineral, estrogen, and testosterone metabolism in postmenopausal women. *FASEB J., 1* (5), 394–397. URL: http://www.fasebj.org/cgi/reprint/1/5/394 (accessed 05.13.2008).

[7] Hajjar, et al. 2001. Impact of diet on blood pressure and age-related changes in blood pressure in the US population: Analysis of HNANES III. *Arch. Intern. Med., 161* (4), 589–593. URL: http://archinte.ama-assn.org/cgi/content/full/161/4/589 (accessed 05.28.2008).

Nutrient	Adult RDA or AI	Common therapeutic range for bone health (daily intake)	Dietary considerations concerning adequacy of average daily intake	Your intake
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 A	2997 IU adult males 2331 IU adult females	5000 IU or less	44% of US population has intake below EAR.[8]	
Vitamin B_6	1.3–1.7 mg adult males 1.3–1.5 adult females	25–50 mg	Studies indicate widespread inadequate vitamin B6 consumption among all sectors of the population;[9] >50% of population consume <70% RDA.	
Folic acid/folate (vitamin B_9)	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,[10] 49% of participants in NHANES survey had intakes below estimated average requirement (EAR).[11] Anywhere from 5–50% of population (varying by geographic region and ethnicity) have genetic variants that impact the ability to optimally metabolize folate.[12]	
Vitamin B_{12}	2.4 mcg adults	10–1000 mcg	Up to 40% of US population have marginal B_{12} status.[13] Older people and vegans are especially at risk.[14]	

[8] Moshfegh, A., et al. 2005.
[9] Serfontein, W., et al. 1984. Vitamin B_6 revisited. Evidence of subclinical deficiencies in various segments of the population and possible consequences thereof. *S. Afr. Med. J., 66* (12), 437–440. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/6385307 (accessed 05.13.2008).
[10] Brown, 2005.
[11] Song, W., et al. 2005. Serum homocysteine concentration of US adults associated with fortified cereal consumption. *J. Am. Coll. Nutr., 24* (6), 503–509. URL: http://www.jacn.org/cgi/content/full/24/6/503 (accessed 06.17.2008).
[12] Botto, L., & Yang, Q. 2000. 5,10-Methylenetetrahydrofolate reductase gene variants and congenital anomalies: A HuGE review. *Am. J. Epidem., 151* (6), 862. URL: http://www.ajcn.org/cgi/reprint/87/3/734 (accessed 07.21.2008).
[13] McBride, J. 2000. B_{12} Deficiency may be more widespread than thought — August 1, 2000 — News from the USDA Agricultural Research Service. URL: http://www.ars.usda.gov/IS/pr/2000/000802.htm (accessed 06.17.2008).
[14] Brown, 2005.

Nutrient	Adult RDA or AI	Common therapeutic range for bone health (daily intake)	Dietary considerations concerning adequacy of average daily intake	Your intake
Vitamin C	90 mg adult males 75 mg adult females	Oral 500–3000 mg (and upward to bowel tolerance[15]), 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).[16]	
Vitamin D	200 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 up to a billion people worldwide are deficient.[17] Deficiency is especially common among the 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.	
Vitamins K_1 and K_2	K_1: 120 mcg adult males 90 mcg adult females K_2: No recommended intake	K_1: 1000 mcg K_2: 45 mcg–180 mcg MK-7 (menaquinone-7)	K_1: Averages 45–150 mcg, which is well below the recommended AI.[18] K_2: Average US intake 9–12 mcg (if any)	
Other nutrients				
Fats	Should comprise minimum of 7% total calories. Generally not to exceed 30% 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.[19]	

[15] PDRHealth. [No date listed]. Vitamin C | Herbal remedies, supplements | PDRHealth. URL: http://www.pdrhealth.com/drugs/altmed/altmed-mono.aspx?contentFileName=ame0173.xml&contentName=Vitamin+C&contentId=336 (accessed 05.13.2008).

[16] Moshfegh, A., et al. 2005.

[17] Holick, M. 2007. Vitamin D deficiency. *New Eng. J. Med., 357* (3), 266–281. URL: http://content.nejm.org/cgi/content/full/357/3/266 (accessed 05.28.2008).
Kimlin, M., et al. 2007. Location and vitamin D synthesis: Is the hypothesis validated by geophysical data? *J. Photochem. Photobiol., 86* (3), 234–249. URL: http://www.ncbi.nlm.nih.gov/pubmed/17142054 (accessed 05.20.2008).

[18] Booth, S., & Suttie, J. 1998. Dietary intake and adequacy of vitamin K. *J Nutr., 128* (5), 785–788. Review. URL: http://jn.nutrition.org/cgi/content/full/128/5/785 (accessed 05.28.2008).

[19] Brown, 2005.

Nutrient	Adult RDA or AI	Common therapeutic range for bone health (daily intake)	Dietary considerations concerning adequacy of average daily intake	Your intake
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[20]	1.0–1.5 g/kg	Daily intake commonly exceeds 100 g, but the elderly and some women often have very deficient intake.[21] Higher protein intake should be balanced with higher RDA level potassium intake from food sources.	

[20] National Academy of Sciences. Institute of Medicine. Food and Nutrition Board. [No publication date listed.] 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 (accessed 05.06.2008).

[21] Brown, 2005.

***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 existing Recommended Daily Allowances (RDA), which is the system currently still in use in food nutrition labeling.[a] 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)*.

- *Recommended Dietary Allowances* (RDA) represent 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.[b] The RDA's reflect 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 from: National Academy of Sciences, Institute of Medicine, Food and Nutrition Board, through the United States Department of Agriculture Food and Nutrition Information Center website. Dietary Reference Intakes for individuals.

- *Adequate Intake* (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 include 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).[c]

Keep in mind that these systems and the nutrient values they represent were established to cover nutritional adequacy for most folks, not for optimizing health! The common therapeutic dose for healthy and strong bones may be higher for most, and significantly higher in "special need" cases.[d]

[a] Wikipedia.org. Dietary Reference Intake. URL: http://en.wikipedia.org/wiki/Dietary_Reference_Intake (accessed 05.06.2008).
[b] *Ibid.*
[c] Moshfegh, A., et al. 2005. What we eat in America, NHANES 2001–2002: Usual nutrient intakes from food compared to Dietary Reference Intakes. US Department of Agriculture, Agricultural Research Service. URL: http://www.ars.usda.gov/SP2UserFiles/Place/12355000/pdf/usualintaketables2001-02.pdf (accessed 06.17.2008).
[d] Palacios, C. 2006. The role of nutrients in bone health, from A to Z. *Crit. Rev. Food Sci. Nutr., 46* (8), 621–628. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/17092827 (accessed 05.13.2008).

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.[22] 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![23] 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.[24][25]

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[26] of at least 32–34 ng/mL), all the calcium in the world will result in little material gain for our bones.[27] 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

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[22] Larsen, T., et al. 2000. Whole small fish as a rich calcium source. *Br. J. Nutr., 83* (2), 191–196. URL (accessed): http://www.ncbi.nlm.nih.gov/pubmed/10743499 (accessed 05.06.2008).
Hansen, M., et al. 1998. Calcium absorption from small, soft-boned fish. *J. Trace Elem. Med. Biol., 12* (3), 148–154. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/9857327 (accessed 05.06.2008).
Heaney, R., & Weaver, C. 1990. Calcium absorption from kale. *Am. J. Clin. Nutr., 51*, 656–657. URL: http://www.ajcn.org/cgi/reprint/51/4/656 (accessed 05.06.2008).

[23] Weaver, C., et al. 1999. Choices for achieving adequate dietary calcium with a vegetarian diet. *Am. J. Clin. Nutr., 70* (Suppl.), 543S–548S.

[24] Heaney, R., & Weaver, C. 2003. Calcium and vitamin D. *Endocrinol. Metab. Clin. N. Am., 32* (1), 181–194, vii–viii. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/12699298 (accessed 05.20.2008).

[25] Murray, M., & Pizzorno, J. 1998. *Encyclopedia of Natural Medicine*, 459. Roseville, CA: Prima Publishing.

[26] Brown, S. 2008. Vitamin D and fracture reduction: An evaluation of the existing research. *Alt. Med. Rev., 13* (1), 21–33. URL (PDF): http://www.thorne.com/altmedrev/.fulltext/13/1/21.pdf (accessed 05.22.2008).

[27] Heaney, R., & Weaver, C. 2003. Calcium and vitamin D. *Endocrinol. Metab. Clin. N. Am., 32* (1), 181–194, vii–viii. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/12699298 (accessed 05.20.2008).
Heaney, R., et al. 2003. Calcium absorption varies within the reference range for serum 25–hydroxyvitamin D. *J. Am. Coll. Nutr., 22* (2) 142–146. URL: http://www.jacn.org/cgi/content/full/22/2/142 (accessed 05.22.2008).

explanation.[28] 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.[29] Calcium carbonate is often found not to be as well absorbed as citrate,[30] 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.[31] For more on how bone serves as a calcium reserve for everyday body processes, see our article on the natural approach to bone health. See also our list of calcium-rich foods for the best dietary sources of this important bone-building mineral.

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Key minerals for bone health — 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*;

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[28] Randall, T. 1992. Longitudinal study pursues questions of calcium, hormones, and metabolism in life of skeleton. *JAMA, 268* (17), 2357–2358.

[29] Sakhaee, K., et al. 2004. Stone forming risk of calcium citrate supplementation in healthy postmenopausal women. *J. Urol., 172* (3), 958–961. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/15311008 (accessed 05.06.2008).

[No author listed.] 1986. Citrate for calcium nephrolithiasis. *Lancet, 1* (8487), 955.

Wabner, C., & Pak, C. 1992. Modification by food of the calcium absorbability and physiochemical effects of calcium citrate. *J. Am. Coll. Nutr., 11*, 548–552. URL: (abstract): http://www.ncbi.nlm.nih.gov/pubmed/1452953 (accessed 05.06.2008).

[30] Heller, H., et al. 2000. Pharmacokinetic and pharmacodynamics comparison of two calcium supplements in postmenopausal women. *J. Clin. Pharmacol., 40* (11), 1237–1244. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/11075309 (accessed 05.28.2008).

[31] Peck W., et al. 1991. *Physician's Resource Manual on Osteoporosis.* Washington, DC: National Osteoporosis Foundation.

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).[32] 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.[33] This high phosphorus-to-calcium ratio can be detrimental to our bones.[34]

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Key minerals for bone health — 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.

Magnesium 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*, a function of which is to regulate bone breakdown in a number of ways.

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*.[35] The enzyme required for forming new calcium crystals, *alkaline phosphatase*, also

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[32] Food and Nutrition Board, Institute of Medicine. 1997. Phosphorus. In Dietary Reference Intakes: Calcium, Phosphorus, Magnesium, Vitamin D, and Fluoride, 146–189. Washington, D.C.: National Academy Press. URL: http://www.nap.edu/books/0309063507/html/index.html (accessed 05.20.2008).
[33] Moshfegh, A., et al. 2005. What we eat in America, NHANES 2001–2002: Usual nutrient intakes from food compared to dietary reference intakes. URL: http://www.ars.usda.gov/SP2UserFiles/Place/12355000/pdf/usualintaketables2001-02.pdf (accessed 05.13.2008).
[34] Worthington–Roberts, B. 1981. *Contemporary Developments in Nutrition,* 240–253. St. Louis, MO: Mosby Co. ISBN= 0801656273.
Linkswiler, H., et al. 1981. Protein-induced hypercalciuria. *Fed. Proc., 40* (9), 2429–2433. URL: http://www.ncbi.nlm.nih.gov/pubmed/7250387 (accessed 05.06.2008).
[35] Medalle, R., et al. 1976. Vitamin D resistance in magnesium deficiency. *Am. J. Clin. Nutr., 29,* 854–858. URL: http://www.ajcn.org/cgi/reprint/29/8/854 (accessed 05.12.2008).

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.[36]

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 into the blood stream in times of need. Adequate daily intake of magnesium is important throughout life to keep the magnesium that is 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.[37]

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.[38]

There has been conflicting opinion about the need for concern about the adequacy of our magnesium intake.[39] Despite its recognized importance, most Americans consume less than the Estimated Average Requirement (EAR) for magnesium.[40] In fact, as of 2001, 56% of the US population was not consuming the Estimated Average Requirement for this mineral.[41]

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[36] Rude, R., et al. 2006. Reduction of dietary magnesium by only 50% in the rat disrupts bone and mineral metabolism. *Osteoporos. Int., 17* (7), 1022–1032. URL (abstract) http://www.ncbi.nlm.nih.gov/pubmed/16601920 (accessed 05.12.2008).
Rude, R., et al. 2005. Dietary magnesium reduction to 25% of nutrient requirement disrupts bone and mineral metabolism in the rat. *Bone, 37* (2), 211–219. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/15923157 (accessed 05.12.2008).
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Iseri, L., & French, J. 1984. Magnesium: Nature's physiologic calcium blocker. *Am. Heart J., 108,* 188–193.
[37] Cohen, L, & Kitzes, R. 1981. Infrared spectroscopy and magnesium content of bone mineral in osteoporotic women. *Israel J. Med. Sci., 17,* 1123–1125. URL: http://www.ncbi.nlm.nih.gov/pubmed/7327911 (accessed 03.03.2010).
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Gaby, A., & Wright, J. 1988. Nutrients and bone health. *Health World,* 29–31.
Hegsted, D. 1967. Mineral intake and bone loss. *Fed. Proceedings, 26* (6), 1747–1763.
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[39] Pennington, J. 1996. Intakes of minerals from diets and foods: Is there a need for concern? *J. Nutr., 126* (9 Suppl.), 2304S–2308S. URL: http://jn.nutrition.org/cgi/reprint/126/9_Suppl/2304S (accessed 05.13.2008).
[40] Hunt, C., & Johnson, L. 2006. Magnesium requirements: New estimations for men and women by cross-sectional statistical analyses of metabolic magnesium balance data. *Am. J. Clin. Nutr., 84* (4), 843–852. URL: http://www.ajcn.org/cgi/content/full/84/4/843 (accessed 05.13.2008).
Moshfegh, A., et al. 2005. What we eat in America, NHANES 2001–2002: Usual nutrient intakes from food compared to dietary reference intakes. URL: http://www.ars.usda.gov/SP2UserFiles/Place/12355000/pdf/usualintaketables2001-02.pdf (accessed 05.13.2008).

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Key minerals for bone health — chromium

Chromium helps to keep insulin activity in the body efficient,[42] an effect that may be bone-protective in a couple of ways:

- by promoting the production of collagen by our bone-*building* cells (called *osteoblasts*); and
- by moderating bone breakdown (*resorption*).

This latter effect was demonstrated in a study where postmenopausal women supplementing with the insulin-sensitizing nutrient chromium picolinate were found to have less calcium and collagen protein molecules in their urine.[43]

A third bone-protective aspect was identified in a similar study, where along with improving insulin regulation and lowering calcium excretion, supplementing with chromium picolinate raised blood levels of DHEA, a hormone that may play a physiological role in preserving bone density among postmenopausal women.[44]

Chromium absorption from foods tends to be poor, and according to Dr. Richard Anderson of the Beltsville Human Nutrition Research Center in Maryland, chromium levels in the blood can also be diminished by a number of stressors: high sugar intake, intense exercise, pregnancy, breastfeeding, infection, and physical injury. Chromium levels also tend to diminish with age. These concerns can all be

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Food & Nutrition Board, Institute of Medicine. 1997. Dietary reference intakes for calcium, phosphorus, magnesium, vitamin D, and fluoride. Washington, DC: National Academy Press.

[41] Moshfegh, A., et al. 2005. What we eat in America, NHANES 2001–2002: Usual nutrient intakes from food compared to dietary reference intakes. URL: http://www.ars.usda.gov/SP2UserFiles/Place/12355000/pdf/usualintaketables2001-02.pdf (accessed 05.13.2008).

[42] Martin, J., et al. 2006. Chromium picolinate supplementation attenuates body weight gain and increases insulin sensitivity in subjects with type 2 diabetes. *Diabetes Care, 29* (8), 1826–1832. URL: http://care.diabetesjournals.org/content/29/8/1826.long (accessed 10.20.2009).

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[43] McCarty, M. 1995. Anabolic effects of insulin on bone suggest a role for chromium picolinate in preservation of bone density. *Med. Hypotheses, 45* (3), 241–246. URL: http://www.ncbi.nlm.nih.gov/pubmed/8569546 (accessed 10.20.2009).

[44] Evans, G., et al. 1995. Chromium picolinate decreases calcium excretion and increases dehydroepiandrosterone (DHEA) in postmenopausal women. *FASEB J., 9*, A449. [As quoted in Lamson, D., & Plaza, S. 2002. The safety and efficacy of high-dose chromium. *Altern. Med. Rev., 7* (3), 218–235. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/12126463 (accessed 10.20.2009).]

addressed by supplementing with a medical-grade bone formulation containing certain chelated forms of chromium, such as chromium polynicotinate or chromium picolinate.[45]

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Key minerals for bone health — 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.[46]

Populations with higher intakes of plant-based foods have higher silica intakes than do Western populations;[47] and not surprisingly, the incidence of hip fractures in these communities is also lower.[48] 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.[49] Of interest is that the major source of

[45] Anderson, R. "Chromium in Health and Disease." Council for the Advancement of Diabetes Research and Education (CADRE) Chromium Summit. April 2003. Boston, Massachusetts.

[46] Bae, Y., et al. 2008. Short-term administration of water-soluble silicon improves mineral density of the femur and tibia in ovariectomized rats. *Biol. Trace Elem. Res.* Apr 26 [Epub ahead of print]. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/18438624 (accessed 05.13.2008).
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Davies, S. & Stewart, A. 1987. *Nutritional Medicine: The Drug-free Guide to Better Family Health.* London/Sydney: Pan Books. ISBN = 0330288334
Carlisle, E. 1975. Silicon with the osteoblast, the bond-forming cell. *Fed. Proc., 34,* 927.
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[47] Anderson, J. 1999. Plant-based diets and bone health: nutritional implications. *Am. J. Clin. Nutr., 70* (3) (Suppl,), 539S–542S. URL: http://www.ajcn.org/cgi/content/full/70/3/539S (accessed 05.28.2008).
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Anasuya, A., et al. 1996. Fluoride and silicon intake in normal and endemic fluorotic areas. *J. Trace Elem. Med. Biol., 10* (3), 149–155. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/8905558 (accessed 05.28.2008).

[48] Gullberg, B., et al. 1997. World-wide projections for hip fracture. *Osteoporos. Int., 7*, 407–413. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/9425497 (accessed 05.28.2008).

[49] Kamen, B., et al. 1984. *Osteoporosis: What It Is, How to Prevent It, How to Stop It*, 222. NY: Pinnacle Books. ISBN: 1558171711

silica in American men's diets was found to be beer and bananas, while in women it was bananas and string beans![50]

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Key minerals for bone health — 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.[51] 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.[52] 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.[53]

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Key minerals for bone health — 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.

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[50] Jugdaohsingh, R., et al. 2002. Dietary silicon and absorption. *Am. J. Clin. Nutr., 75* (5), 887–893. URL: http://www.ajcn.org/cgi/content/full/75/5/887 (accessed 05.28.2008).

[51] Kimmel, P., et al. 1992. Zinc nutritional status modulates the response of 1,25-dihydroxycholecalciferol to calcium depletion in rats. *J. Nutr., 122* (7):1576–1581. URL: http://jn.nutrition.org/cgi/reprint/122/7/1576 (accessed 05.13.2008).
Teller, E., et al. 1987. Zinc (Z) nutritional status modulates the 1,25(OH)2D(125) response to low calcium (LC) diet (D). *Kidney Int., 31*, 358.

[52] Hambidge, M. 2000. Human zinc deficiency. *J. Nutr., 130* (5), 1344S–1349S. URL: http://jn.nutrition.org/cgi/content/full/130/5/1344S (accessed 07.21.2008).

[53] Johtatsu, T., et al. 2007. Serum concentrations of trace elements in patients with Crohn's disease receiving enteral nutrition. *J. Clin. Biochem. Nutr., 41* (3), 197–201. URL: http://www.pubmedcentral.nih.gov/articlerender.fcgi?tool=pubmed&pubmedid=18299716 (accessed 05.13.2008).
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Atik, S. 1983. Zinc and senile osteoporosis. *J. Am. Ger. Soc., 31* (12), 790–791. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/6655182 (accessed 05.13.2008).

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.[54] 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.[55] 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%.[56] Other dietary patterns can inhibit the absorption of manganese, such as getting too much calcium, phosphorus, iron, or zinc.[57]

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.[58] Osteoporotic changes in bone can be brought about by manganese deficiency, which appears to increase bone breakdown while decreasing new bone mineralization.[59] 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.[60] Fortunately, manganese deficiency is relatively easy to address and dietary sources are extremely safe.

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Key minerals for bone health — 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.

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[54] Greger, J. 1998. Dietary standards for manganese: Overlap between nutritional and toxicological studies. *J. Nutr., 128* (2), 368S–371S. URL: http://jn.nutrition.org/cgi/content/full/128/2/368S (accessed 05.13.2008).

[55] Raloff, J. 1986. Reasons for boning up on manganese. [Review.] *Science News, 130,* 199.
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[56] Pennington, J., & Young, B. 1991. Total Diet Study nutritional elements 1982–1989. *J. Am. Diet. Assoc., 91* (2), 179–183. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/1991931 (accessed 05.13.2008).

[57] Freeland–Graves, J., et al. 1987. "Manganese requirements of humans." In *Nutritional Bioavailability of Manganese*. ed. C. Keys. Washington, DC: Am. Chem. Soc. ISBN: 0841214336.
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[58] Strause, L., & Saltman, P. 1987. "Role of manganese in bone metabolism." In *Nutritional Bioavailability of Manganese*. ed. C. Keys. Washington, DC: Am. Chem. Soc. ISBN: 0841214336.

[59] Slemenda, C., et al. 1990. Predictors of bone mass in perimenopausal women. A prospective study of clinical data using photon absorptiometry. *Ann. Intern. Med., 112* (2), 96-101. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/2294827 (accessed 05.13.2008).

[60] Reginster, J.Y., et al. 1988. Trace elements and postmenopausal osteoporosis: A preliminary study of decreased serum manganese. *Med. Sci. Res., 16*, 337–338.

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.[61] And as with so many other minerals, copper excretion from the body is increased on a diet high in sugar, other sweeteners like fructose,[62] and refined flour.[63] Some researchers have suggested that even lactose (milk sugar) could interfere with copper metabolism, making high dairy intake less than ideal for copper utilization.[64] 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.[65]

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Key minerals for bone health — boron

Boron is another element on our list of 20 key nutrients 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.[66] 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.[67]

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[61] Strain, J. 1988. A reassessment of diet and osteoporosis — possible role for copper. *Med. Hypotheses, 27* (4), 333–338. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/3067062 (accessed 05.13.2008).
Strause, L., et al. 1986. Effects of long-term dietary manganese and copper deficiency on rat skeleton. *J. Nutr., 116* (1), 135-41. URL: http://jn.nutrition.org/cgi/reprint/116/1/135 (accessed 05.13.2008).
Raloff, J. 1986.

[62] Turnlund, J. 1999. "Copper," in *Modern Nutrition in Health and Disease,* ed. M.E. Shils et al., pp. 241–252. Baltimore: Lippincott Williams & Wilkins.

[63] Hallfrisch, J., et al. 1987.

[64] Strain, J. 1988.

[65] Pennington, J. 1996.
Pennington, J. & Young, B. 1991.
Pennington, J., et al. 1986. Mineral content of food and total diet: The Selected Minerals in Foods Survey, 1982 to 1984. *J. Am. Diet. Assoc., 86* (7), 876–891. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/3722652 (accessed 05.13.2008).
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[66] Samann, S., et al. 1998. The nutritional and metabolic effects of boron in humans and animals. *Biol. Trace Elem. Res., 66* (1–3), 227–235. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/10050922 (accessed 05.13.2008).
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[67] Neilsen, F. 1995. Personal communication with Dr. Susan Brown.

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, and this could in part 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.[68]

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Key minerals for bone health — 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 guardianship 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.[69]

Diets low in potassium increase net urinary calcium loss, whereas diets high in potassium reduce it.[70] 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![71] 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[72] — all the more motivation for us to renew our "5–10-a-day" pledge![73]

(See my blog post on how to measure your daily pH balance and track potential bone loss, or read my full article on testing markers of bone resorption.)

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[68] Gaby, A. 1994. *Preventing and Reversing Osteoporosis: What You Can Do About Bone Loss — A Leading Expert's Natural Approach to Increasing Bone Mass,* 304. Roseville, CA: Prima Publishing. ISBN: 0761500227

[69] Sebastian, A., et al. 1994. Improved mineral balance and skeletal metabolism in postmenopausal women treated with potassium bicarbonate. *NEJM, 130* (125), 1776–1781. URL (abstract): http://content.nejm.org/cgi/content/abstract/330/25/1776 (accessed 06.04.2008).

[70] Nieves, J. 2005. Osteoporosis: the role of micronutrients. *Am. J. Clin. Nutr., 81* (5), 1232S–1239S. URL: http://www.ajcn.org/cgi/content/full/81/5/1232S (accessed 05.13.2008).

[71] Davies, K., et al. 2002. Dietary potassium conserves calcium after menopause. *J. Bone Miner. Res., 17* (Suppl. 1), S476. Abstract M362.

[72] Tucker, K., et al. 2001. The acid–base hypothesis: Diet and bone in the Framingham Osteoporosis Study. *Eur. J. Nutr., 40* (5), 231–237. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/11842948 (accessed 05.13.2008).

[73] Demigné, C., et al. 2004. Protective effects of high dietary potassium: Nutritional and metabolic aspects. *J. Nutr., 134* (11), 2903–2906. URL: http://jn.nutrition.org/cgi/content/full/134/11/2903 (accessed 05.13.2008).

Key minerals for bone health — 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 provide 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.[74]

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.[75]

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Key vitamins for bone health — vitamin A

Vitamin A plays an essential role in the development of osteoblasts, the bone-building cells that lay down new bone.[76] A deficiency in vitamin A also limits calcium absorption and metabolism, which results in poor bone growth.[77] Overall, low vitamin A levels are associated with osteoporosis and increased risk of fracture.[78]

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[74] Gaby, A. 1994.
[75] Reginster, J.Y., et al. 2004. Strontium ranelate: A new paradigm in the treatment of osteoporosis. *Expert Opin. Investig. Drugs, 13* (7), 857-864. Review. URL (abstract): http://www.expertopin.com/doi/abs/10.1517/13543784.13.7.857 (accessed 05.20.2008).
[76] Kawaguchi, J. 2006. Generation of osteoblasts and chondrocytes from embryonic stem cells. *Methods Mol. Biol., 330*, 135–148. http://www.ncbi.nlm.nih.gov/pubmed/16846022 (accessed 05.13.2008).
[77] Newton, H., et al. 1985. The cause and correction of low blood vitamin C concentrations in the elderly.
[78] Maggio, D., et al. 2006. Low levels of carotenoids and retinol in involutional osteoporosis. *Bone, 38* (2), 244–248. URL: (abstract): http://www.ncbi.nlm.nih.gov/pubmed/16188508 (accessed 03.02.2009).

On the other hand, there is some controversy as to whether *high* vitamin A intakes are actually helpful, or more of a hindrance to bone health.[79] Some studies suggest high vitamin A can be bone-damaging, but this relates only to the active forms of vitamin A, or *retinoids*. The jury is still out on how — or even if — excess vitamin A intake actually increases risk of osteoporosis and bone fracture.[80] But in the meantime, we recommend limiting intake of supplemental vitamin A — that is, preformed vitamin A, or *retinoid* forms — to 5000 IU per day. This is still well below the known tolerable upper limit (UL) of preformed vitamin A — around 10,000 IU per day.

What do we mean by "preformed" vitamin A? There are many forms of vitamin A, with *retinoids* and carotenoids being the two main categories.

- *Retinoids* — natural, fat-soluble forms of vitamin A that are available for immediate use in the body. Derived from animal sources, retinoids are a smaller class than the carotenoids, and include *retinol, retinal*, and *retinoic acid*, among others.
  - *Subgroup: Retinol* — also referred to as "preformed vitamin A," retinol is regarded as the main active form for vitamin A in the body. It is found naturally in some animal tissues, such as liver, which makes liver a good dietary source of this vitamin.
- *Carotenoids* — a large class of natural, fat-soluble pigments found principally in deeply-colored plant foods. Carotenoids, sometimes referred to as *provitamins*, are dietary precursors to the active forms of vitamin A in the body. More than 600 carotenoids have been identified to date.[81]

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[79] Ribaya–Mercado, J., & Blumberg, J. 2007. Vitamin A: Is it a risk factor for osteoporosis and bone fracture? *Nutr. Rev., 65* (10), 425–438. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/17972437 (accessed 05.22.2008).

Macdonald, H., et al. 2004. Nutritional associations with bone loss during the menopausal transition: Evidence of a beneficial effect of calcium, alcohol, and fruit and vegetable nutrients and of a detrimental effect of fatty acids. *Am. J. Clin. Nutr., 79*, 155–165.

Barker, M., & Blumsohn, A. 2003. Is vitamin A consumption a risk factor for osteoporotic fracture? *Proc. Nutr. Soc., 62* (4), 845–850. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/15018484 (accessed 05.22.2008).

Symanski, E., & Hertz–Picciotto, I. 1995. Blood lead levels in relation to menopause, smoking, and pregnancy history. *Am. J. Epidemiol., 141*, 1047–1058.

Melhus, H., et al. 1998. Excessive dietary intake of vitamin A is associated with reduced bone mineral density and increased risk for hip fracture. *Ann. Intern. Med., 129*, 770–778.

[80] Ribaya–Mercado, J., & Blumberg, J. 2007.

Macdonald, H., et al. 2004.

Barker, M., & Blumsohn, A. 2003.

Symanski, E., & Hertz–Picciotto, I. 1995.

Melhus, H., et al. 1998.

[81] Mercadante, A. "New carotenoids: Recent progress." Invited Lecture 2. Abstracts of the 12th International Carotenoid Symposium, 07/18–23/1999, Cairns, Australia.

Ong, A., & Tee, E. 1992. Natural sources of carotenoids from plants and oils. *Meth. Enzymol., 213*, 142–167.

- *Subgroup: Beta-carotene* — the most well-known plant precursor source of active vitamin A. Our bodies can convert beta-carotene into active vitamin A when needed, storing or eliminating any extra.

A full description of the hundreds of forms and functions of vitamin A is beyond the scope of this article, so here are a few key points to remember:

- Most of the vitamin A in our diets comes from plants in the form of beta-carotene, which, again, is a precursor that is safely stored in our body fat and liver, where it gets converted into active vitamin A forms as needed.
- Retinol, the primary form of active vitamin A, can be toxic if consumed at very high levels.
- Thanks to an inbuilt mechanism that shuts off our body's conversion of beta-carotene into retinol when levels are adequate, high intake of beta-carotene is generally not of concern.
- Some recent research has, however, linked high-dose beta-carotene supplements to increased risk of lung cancer among smokers — but the opposite seems to be the case among nonsmokers![82]
- Though there may be different thoughts on what constitutes "high-dose beta-carotene," amounts over 25,000 IU are typically considered to be in the higher range.
- Science is always evolving, but our Better Bones products have been well-formulated based on current nutritional research, and contain useful, nontoxic amounts of both forms as part of supplement regimen.

Today, for the approximately 44% of the US population that under-consume vitamin A in their food, supplementing with both the above-described forms of vitamin A is a wise move for bone health.

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Key vitamins for bone health — vitamin B_6 (pyroxidine)

Vitamin B_6 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:

- B_6 is necessary for *hydrochloric acid* (HCl) production by the stomach, and HCl in turn is necessary for calcium absorption.

- B_6 is necessary for adrenal functioning. In turn, several dozen hormones are produced by the adrenal glands, several of which aid in maintaining proper mineral balance within the body.

[82] Tanvetyanon, T., & Bepler, G. 2008. Beta-carotene in multivitamins and the possible risk of lung cancer among smokers versus former smokers: A meta-analysis and evaluation of national brands. *Cancer, 113* (1), 150–157. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/18429004 (accessed 02.25.2009).

Touvier, M., et al. 2005. Dual association of beta-carotene with risk of tobacco-related cancers in a cohort of French women. *J. Natl. Cancer Inst, 97* (18), 1338–1344. URL: http://jnci.oxfordjournals.org/cgi/content/full/97/18/1338 (accessed 02.25.2009).

- B_6 is also a necessary co-factor in the enzymatic cross-linking of collagen strands, which increase the strength of connective tissue.

- B_6 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. B_6, 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 B_6, and many others function suboptimally without a sufficient amount of this nutrient.[83]

Studies indicate that inadequate vitamin B_6 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 B_6.[84]

One of the factors contributing to this problem is the relative instability of vitamin B_6, which is destroyed by light and heat. As a result, much of it is lost in food processing, storage, and preparation. In addition, higher animal protein intake creates an increased demand for B_6, as do other common B_6 antagonists such as yellow dye #5 (food coloring), oral contraceptives, and certain other drugs and alcohol.[85]

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Key vitamins for bone health — folic acid and folate — forms of the water-soluble vitamin B_9

Folic acid is another one of the B vitamins, referred to sometimes as folate (its related anion form), or simply as vitamin B_9. 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 fracture risk.

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, their ability to prevent homocysteine build-up, detoxify adequately, and keep inflammation at bay.[86]

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[83] Serfontein, W., et al. 1984. Vitamin B_6 revisited. Evidence of subclinical deficiencies in various segments of the population and possible consequences thereof. *S. Afr. Med. J., 66* (12), 437–440. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/6385307 (accessed 05.13.2008).

[84] Azuma, J., et al. 1976. Apparent deficiency of vitamin B_6 in typical individuals who commonly serve as normal controls. *Res. Commun. Chem. Pathol. Pharmacol., 14* (2), 343–348. URL (abstract) http://www.ncbi.nlm.nih.gov/pubmed/940965 (accessed 05.13.2008).

[85] Kishi, H., et al. 1977. Deficiency of vitamin B_6 in women taking contraceptive formulations. *Res. Commun. Chem. Pathol. Pharmacol., 17* (2), 283–293. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/877413 (accessed 05.13.2008).
Brown, J. 1990. *The Science of Human Nutrition*. NY: Harcourt Brace Jovanovich. ISBN: 015578689X.
Azuma, J., et al. 1976.

[86] Botto & Yang. 2000.

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.

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Key vitamins for bone health — vitamin B_{12} (cobalamin)

Because of their role in the detoxification of *homocysteine*, vitamins B_6, B_{12}, and folic acid (B_9) have all been recently added to our list of important bone-protective nutrients.[87] Osteoblasts, the body's bone-building cells, require an adequate supply of B_{12}, or their ability to function properly will be compromised.[88] Vitamin B_{12} deficiency anemia has been associated with osteoporosis, and having low serum levels of vitamin B_{12} has also been associated recently with odds of frailty in older women.[89]

Following careful analysis of the Framingham Offspring Study in 2000, Tufts nutritional epidemiologist Katherine Tucker concluded that B_{12} deficiency may be more widespread than previously thought, with nearly 40% of the US population "flirting" with marginal B_{12} status, according to the USDA website.[90]

Vitamin B_{12} is not found in plants, but is abundant in animal protein. Yet vitamin B_{12} 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 B_{12} — 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 B_{12} absorption could be due

[87] Brown, S. 2006. Bone nutrition. In *Scientific Evidence for Musculoskeletal, Bariatric, and Sports Nutrition*, ed. I. Kohlstadt, p. 458. Boca Raton, FL: CRC Press. ISBN = 0849337240
[88] Carmel, R. et al. 1988. Cobalamin and osteoblast–specific proteins. *NEJM, 319* (2), 70–75. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/3260008 (accessed 05.13.2008).
[89] Matteini, A., et al. 2008. Markers of B-vitamin deficiency and frailty in older women. *J. Nutr. Health Aging, 12* (5): 303–308. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/18443711 (accessed 05.06.2008).
[90] B12 deficiency may be more widespread than thought. URL: http://www.ars.usda.gov/IS/pr/2000/000802.htm (accessed 06.17.2008).

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.[91]

B_{12} is also one of the few vitamins biosynthesized by the "friendly" flora in our intestines.[92] Though production in the human intestines is not believed to occur to an extensive degree, there is still a lot for us to learn about both B_{12} synthesis and absorption processes, and it is safe to say that maintaining healthy gut flora is one way to encourage adequate vitamin B_{12} status as well as promote good bone health. After all, the B_{12} we get from animal sources originally derives from bacterial production, for instance in the rumen of cows.

Even so, vegetarians are strongly suggested to ensure adequate B12 intake — a high-quality daily supplement formulated to deliver the most highly bioavailable forms of key bone nutrients, such as those offered in our Better Bones programs, can be very helpful!

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Key vitamins for bone health — 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[93] — 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

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[91] McBride, J. 2000. Are you vitamin B12 deficient? *Ag. Res. Mag., 48* (8). URL (PDF): http://www.ars.usda.gov/is/AR/archive/aug00/vita0800.pdf (accessed 06.17.2008).

[92] Santos, F., et al. 2008. The complete coenzyme B_{12} biosynthesis gene cluster of *Lactobacillus reuteri* CRL1098. *Microbiology, 154* (Pt 1), 81–93. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/18174128 (accessed 05.22.2008).

[93] Goralczyk, R., et al. 1992. Regulation of steroid hormone metabolism requires L–ascorbic acid. *Ann. N Y Acad. Sci., 669*, 349–351.
Freudenheim, J., et al. 1986.

would be greatly served on many levels by a much higher intake per day.[94] 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.

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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.[95] 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's beneficial effects throughout the body. Inadequate levels of vitamin D have now been associated with numerous types of cancer,

[94] Pauling, L. 1986. *How to Live Longer and Feel Better.* Corvallis, OR: Oregon State University Press. ISBN: 0870710966

[95] Holick, M. 2006. High prevalence of vitamin D inadequacy and implications for health. *Mayo Clin. Proc., 81* (3), 353–373. URL: http://www.ncbi.nlm.nih.gov/pubmed/16529140 (accessed 05.13.2008).
Hanley, D., & Davison, K. 2005. Vitamin D insufficiency in North America. Symposium: Vitamin D Insufficiency: A Significant Risk Factor in Chronic Diseases and Potential Disease-Specific Biomarkers of Vitamin D Sufficiency. *J. Nutr., 135* (2), 332-337. URL: http://jn.nutrition.org/cgi/content/full/135/2/332 (accessed 05.13.2008).
Holick, M. 2005. The vitamin D epidemic and its health consequences. *J. Nutr., 135* (11), 2739S–2748S. URL: http://jn.nutrition.org/cgi/content/full/135/11/2739S (accessed 05.13.2008).

cardiovascular disease, hypertension, stroke, diabetes, multiple sclerosis, rheumatoid arthritis, periodontal disease, macular degeneration, mental illness, propensity to fall, and chronic pain.[96]

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.[97]

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.[98] 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.[99]

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.[100] And indeed, as the Better Bones Center recently documented in *Alternative Medicine Review*, various clinical trials support this amazing fracture-reduction capacity of adequate-dose vitamin D.[101]

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[96] Cannell, J., et al. 2008. Uses of vitamin D in clinical practice. *Alt. Med. Rev., 13* (1). URL (PDF): http://www.thorne.com/altmedrev/.fulltext/13/1/6.pdf (accessed 06.02.2008).

[97] [No author listed.] 2008. Healthday. MedlinePlus: Low levels of vitamin D spell trouble for breast cancer patients. URL: http://www.nlm.nih.gov/medlineplus/news/fullstory_64701.html (accessed 05.28.2008).
Grayson, A. 2008. ABC News: Low vitamin D may mean worse breast cancer. More aggressive breast cancer linked to vitamin D deficiency. URL: http://abcnews.go.com/Health/OnCallPlusBreastCancerNews/story?id=4866328&page=1 (accessed 05.28.2008).

[98] Bischoff–Ferrari, H., et al. 2007. Calcium intake and hip fracture risk in men and women: A meta-analysis of prospective cohort studies and randomized controlled trials. *Am. J. Clin. Nutr., 86* (6), 1780–1790. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/18065599 (accessed 06.17.2008).
Steingrimsdottir, L., et al. 2005. Relationship between serum parathyroid hormone levels, vitamin D sufficiency, and calcium intake. *JAMA, 294* (18), 2336-2341. URL: http://jama.ama-assn.org/cgi/content/full/294/18/2336 (accessed 06.17.2008).
Dawson-Hughes, B., et al. 1997. Effect of calcium and vitamin D supplementation on bone density in men and women 65 years of age or older. *NEJM*, 337 (10), 670-676. URL: http://content.nejm.org/cgi/content/full/337/10/670 (accessed 06.17.2008).
Dawson–Hughes, B., et al. 1990. A controlled trial of the effect of calcium supplementation on bone density in postmenopausal women. *NEJM, 323* (13), 878–883. URL: http://www.ncbi.nlm.nih.gov/pubmed/2203964 (accessed 05.13.2008).

[99] Dawson–Hughes, B., et al. 1990.

[100] Grant, W. et al. 2005. Comparisons of estimated economic burden due to insufficient solar ultraviolet irradiance for the United States. *Photochem. Photobiol., 81* (6), 1276–1286. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/16159309 (accessed 06.04.2008).

[101] Brown, S. 2008. Vitamin D and fracture reduction: An evaluation of the existing research. *Alt. Med. Rev., 13* (1). URL: (http://www.thorne.com/altmedrev/.fulltext/13/1/21.pdf (accessed 06.04.2008).

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 in 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.[102] Several studies have shown a rapid reduction in falls among the elderly with administration of even 800 IU vitamin D. Two recent clinical trials, for example, showed a reduction in falls of 49% and 72% with just 800 IU supplemental vitamin D.[103] If for 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 across all body tissues are far-reaching *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![104] Our ability to absorb calcium via the intestines is, in fact, directly related to our blood levels of this active form of vitamin D.[105] What's interesting, as calcium expert Dr. Robert Heaney has demonstrated, is that intestinal calcium absorption was 65% higher when blood levels of vitamin D averaged 34 ng/mL — we now know this level approaches only

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[102] Prince, R., et al. 2008. Effects of ergocalciferol added to calcium on the risk of falls in elderly high-risk women. *Arch. Int. Med., 168* (1), 103–108. URL http://www.ncbi.nlm.nih.gov/pubmed/18195202 (accessed 05.13.2008).
Bischoff-Ferrari, H., et al. 2006. Effect of cholecalciferol plus calcium on falling in ambulatory older men and women: A 3-year randomized controlled trial. URL: http://archinte.ama-assn.org/cgi/content/full/166/4/424 (accessed 05.13.2008).
Flicker, L., et al. 2005. Should older people in residential care receive vitamin D to prevent falls? Results of a randomized trial. *J. Am. Geriatrics Soc., 53* (11), 1881. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/16274368 (accessed 05.13.2008).
Freudenheim, J., et al. 1986. Relationships between usual nutrient intake and bone mineral content of women 35–65 years of age: Longitudinal and cross-sectional analysis. *Am. J. Clin. Nutr., 44* (6), 863–876. URL: http://www.ajcn.org/cgi/reprint/44/6/863 (accessed 05.13.2008).

[103] Broe, K., et al. 2007. A higher dose of vitamin D reduces the risk of falls in nursing home residents: A randomized, multiple-dose study. *J. Am. Geriatr. Soc., 55* (2), 234–239. URL: http://www.medscape.com/viewarticle/553365 (accessed 06.04.2008).
Bischoff, H., et al. 2003. Effects of vitamin D and calcium supplementation on falls: A randomized controlled trial. *J. Bone Miner. Res., 18* (2), 343-351. URL: http://www.ncbi.nlm.nih.gov/pubmed/12568412 (accessed 06.04.2008).

[104] NIH. 1994. Consensus statement. Washington, DC: National Institute on Aging.

[105] Eufemio, M. 1990. Advances in the therapy of osteoporosis. Part VIII. *Ger. Med. Today, 9* (11), 37–49.
Gallagher, J., et al. 1979. Intestinal calcium absorption and serum vitamin D metabolites in normal subjects and osteoporotic patients. *J. Clin. Invest., 64* (3), 729–736. URL: http://www.jci.org/articles/view/109516 (accessed 05.13.2008).

the barest minimum needed to ensure system-wide health.[106] (For more about this, see my blog entry on vitamin D and calcium.)

It's also of note that at *extremely* high levels, supplemental vitamin D can have toxic effects. For most people, this is strictly a *theoretical* concern, and evidence of toxicity in adults consuming more than 10,000 IU/day is absent in the literature.[107] Nevertheless, it is this theoretical risk that 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.[108]

Today we know precisely what levels in the blood are needed for optimal bone health: a minimum of 34 mg/mL, but more ideally, at least 50–60 mg/mL. In reality, many people will need more than 2000 IU vitamin D daily to achieve this minimum adequate blood level. Thus, at the Center for Better bones, 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.

- 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.
- For further reading on vitamin D, see also our other articles:
    - Vitamin D: an old bone builder takes on new importance
    - Vitamin D: its benefits are more than ever imagined

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Key vitamins for bone health — 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.[109] 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

[106] Heaney, R., et al. 2003. Calcium absorption varies within the reference range for serum 25–hydroxyvitamin D. *J. Am. Coll. Nutr., 22* (2), 42–146. URL: http://www.jacn.org/cgi/content/full/22/2/142 (accessed 06.04.2008).
[107] Cannell, J., et al. 2008. Diagnosis and treatment of vitamin D deficiency. Review. *Expert Opin. Pharmacother., 9* (1), 1–12. URL (summary): http://www.expertopin.com/doi/abs/10.1517/14656566.9.1.107 (accessed 05.22.2008).
[108] Vieth, R., et al. 2001. Efficacy and safety of vitamin D intake exceeding the lowest observed adverse effect level. *Am. J. Clin. Nutr., 73* (2), 288–294. URL: http://www.ajcn.org/cgi/content/full/73/2/288 (accessed 06.04.2008).
[109] Gaby, A. 1994.

fragile and easily broken. Vitamin K also aids in the binding of calcium to the bone matrix[110] — in essence, it serves as the "glue" that binds calcium onto the skeleton.

Just as vitamin K is central to bone *formation*, so it 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 to speed fracture healing.[111]

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 K_1, which is found in plant-based foods, particularly green leafy vegetables; and the *menaquinones*, or K_2, 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 K_1 and K_2 increase bone quality. But vitamin K_2 is more bioavailable, longer lasting, and provides for greater increase in bone strength.[112]

The more we learn about K, the more we see how it takes on various forms and roles in the body. To date most of the research has been done on K_1. But a new wave of research is now focusing on K_2 — in particular the subset of K_2 known as *menaquinone–7*, or *MK–7*. This research documents the superior ability of MK-7 over K_1 to enhance both bone and heart health.[113] Getting enough of the K_2 forms of this

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[110] Wright, J. 1989. Testing for vitamin K_1: An osteoporosis "risk factor," *Int. Clin. Nutr. Rev., 9* (1), 14–15.
Feldman, E. 1988. *Essentials of Clinical Nutrition*. Philadelphia: F. A. Davis Co. ISBN: 0803634315
Tomita, A. 1971. Postmenopausal osteoporosis CA-47 study with vitamin K_2. *Clin. Endocrinol.* (Jpn.)*, 19*, 731.

[111] Hart, J., et al. 1985. Electrochemical detection of depressed circulating levels of vitamin K_1 in osteoporosis. *J. Clin. Endocrinol. Metab., 60* (6), 1268–1269. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/3998071 (accessed 05.13.2008).

[112] Knapen, M., et al. 2007. Vitamin K_2 supplementation improves hip bone geometry and bone strength indices in postmenopausal women. *Osteoporos. Int., 18* (78), 963–972. URL: http://www.pubmedcentral.nih.gov/articlerender.fcgi?tool=pubmed&pubmedid=17287908 (accessed 05.14.2008).
Braam, L., et al. 2003. Vitamin K_1 supplementation retards bone loss in postmenopausal women between 50 and 60 years of age. *Calcif. Tissue Int., 73* (1), 21–26. URL (abstract): http://www.ncbi.nlm.nih.gov/sites/pubmed/14506950 (accessed 05.14.2008).

[113] Schurgers, L., et al. 2007. Vitamin K-containing dietary supplements: Comparison of synthetic vitamin K1 and natto-derived menaquinone-7. *Blood, 108* (8), 3279–3283. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/17158229 (accessed 05.22.2008).
Takemura, H. 2006. [Prevention of osteoporosis by foods and dietary supplements. *"*Kinnotsubu honegenki": A fermented soybean (natto) with reinforced vitamin K2 (menaquinone-7)] [In Japanese.] *Clin. Calcium, 16* (10), 171–172. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/17012826 (accessed 05.22.2008).
Yamachuchi, M., & Ma, Z. 2001. Inhibitory effect of menaquinone–7 (vitamin K_2) on osteoclast–like cell formation and osteoclastic bone resorption in rat bone tissues *in vitro*. *Molecul. Cellul. Biochem., 228* (1–2), 39–49 (9). URL (abstract): http://www.ingentaconnect.com/content/klu/mcbi/2001/00000228/F0020001/00383053 (accessed 05.22.2008).
Tsukamoto, Y., et al. 2000. Intake of fermented soybean (natto) increases circulating vitamin K_2 (menaquinone–7) and gamma-carboxylated osteocalcin concentration in normal individuals. *J. Bone Miner. Metab. 18* (4), 216–222. URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/10874601 (accessed 05.22.2008).
Yamaguchi, M., et al. 1998. Effect of vitamin K_2 (menaquinone–7) in fermented soybean (*natto*) on bone loss in ovariectomized rats. *J. Bone Min. Metab., 17* (1), 23–29. URL (abstract): http://www.springerlink.com/content/xgyn1c0mkl6frhen/ (accessed 05.22.2008).

vitamin has been found to be especially important for healthy bones in patients being treated with oral anticoagulants, such as warfarin (Coumadin).[114] (Read more about vitamin K research at the Better Bones Foundation.)

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.[115] 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.

To learn more, read my article on vitamin K — the overlooked bone builder and heart protector.

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Other key nutrient for 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 more of 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.

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114 Cranenburg, E., et al. 2007. Vitamin K: The coagulation vitamin that became omnipotent. *Thrombos. Haemostasis, 98* (1), 120–125. URL (PDF): http://www.schattauer.de/index.php?id=1268&pii=th07070120&no_cache=1 (accessed 06.17.2008).

115 Krasinski, S., et al. 1985. The prevalence of vitamin K deficiency in chronic gastrointestinal disorders. *Am. J. Clin. Nutr., 41*, 70–75. URL: http://www.ajcn.org/cgi/reprint/41/3/639 (accessed 05.13.2008).

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 *phospholipids*. Finally, essential fatty acids appear to improve bone strength, possibly by fomenting collagen synthesis.[116]

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Other key nutrients in bone health — protein

When it comes to bone nutrition, the situation with protein is somewhat of a paradox — similar to that with fats. While some protein is essential, too much is detrimental. Protein is beneficial for intestinal absorption of calcium, and protein is a major building block for bone.[117] 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 foodstuffs are bad per se — 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.

For more information on chronic low-grade metabolic acidosis, see my article on acid-alkaline balance.

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[116] Kruger, M., & Horrobin, D. 1997. Calcium metabolism, osteoporosis, and essential fatty acids: A review. *Prog. Lipid Res., 36* (2–3), 131–151. URL: http://www.ncbi.nlm.nih.gov/pubmed/9624425 (accessed 05.13.2008).
[117] Dawson–Hughes, B., & Harris, S. 2002. Calcium intake influences the association of protein intake with rates of bone loss in elderly men and women. *Am. J. Clin. Nutr., 75* (4), 773–779. URL: http://www.ajcn.org/cgi/content/full/75/4/773 (accessed 05.22.2008).