Bone Health

for Female Athletes

GATORADE SPORTS SCIENCE INSTITUTE™

Introduction

Bone health is an important but often overlooked subject for athletes, as well as the general population. Bone density is a critical component to overall health and function throughout the lifespan. Maximizing bone mineral density is crucial because females are particularly susceptible to low bone mineral density, known as osteopenia and osteoporosis. The information below will provide a brief overview of bone physiology, growth and remodeling, the impact of energy and micronutrient intake on bone health, and practical applications to support athlete bone health.

Bone physiology

Structure

The human skeleton is made up of cartilage and bone. It provides the structure of the human body, protects vital organs, serves as an attachment point for muscles, and stores calcium. Bone is one of the hardest materials within the human body, yet it is also very light in weight. The composition of bone includes water, calcium phosphate in the form of hydroxyapatite, and protein in the form of collagen. The structure of healthy bones largely differs to that of osteoporotic bone (i.e., during osteopenia and osteoporosis, Figure 1).

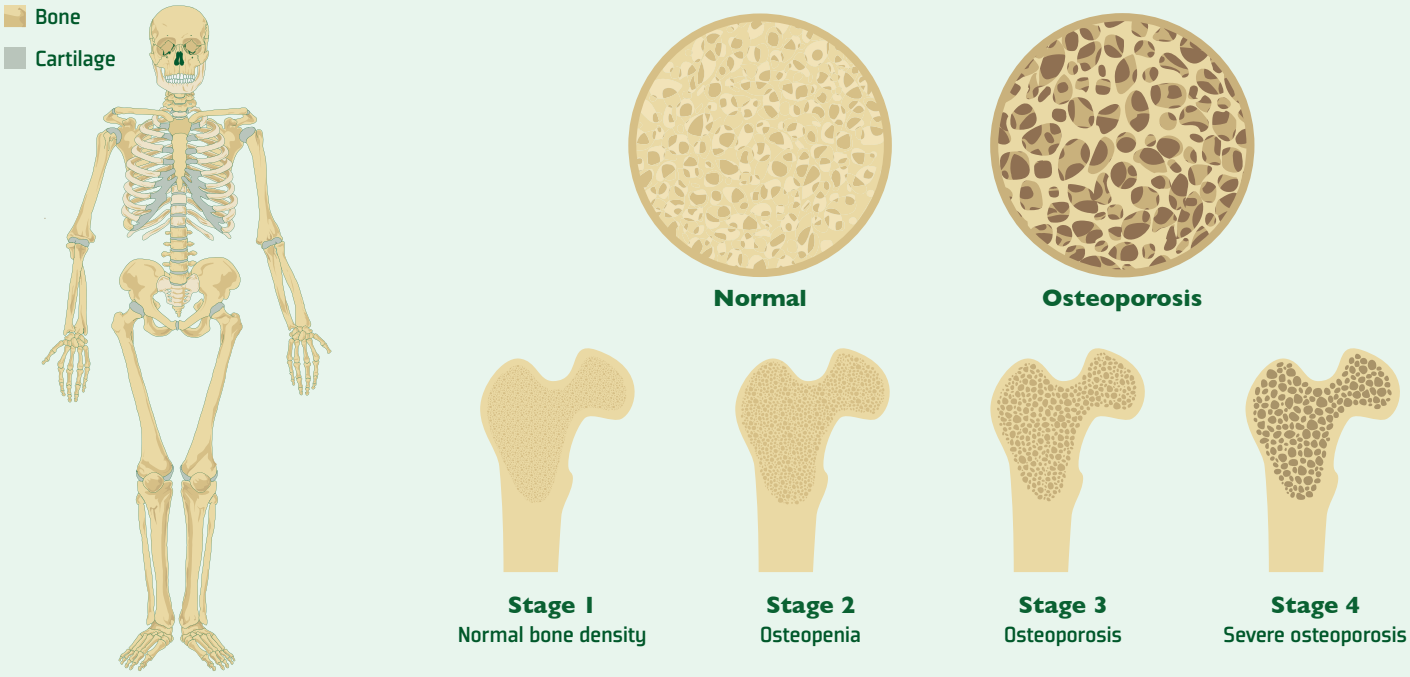


Figure 1: Normal bone vs. osteoporotic bone

Bone formation and turnover

Bone health is regulated by the endocrine system, with multiple hormones influencing the building, maintenance and breakdown of bone, including, but not limited to, parathyroid hormone (PTH) and estrogen. The following section describes the process when the endocrine system is functioning as designed, with adequate energy availability and micronutrient intake from the diet.

Bone modeling and remodeling

Bone modeling is the process of building new bone tissue, and bone remodeling is a process of continuous breakdown and formation (Figure 2). In youth, longitudinal bone modeling occurs at the sites of the epiphysial (growth) plates. Peak bone density is achieved in the first few decades of life. With mechanical loading, bone diameter can continue to grow into adulthood. Specific cells called osteoclasts, osteocytes and osteoblasts are responsible for development, growth and remodeling of bone tissue.

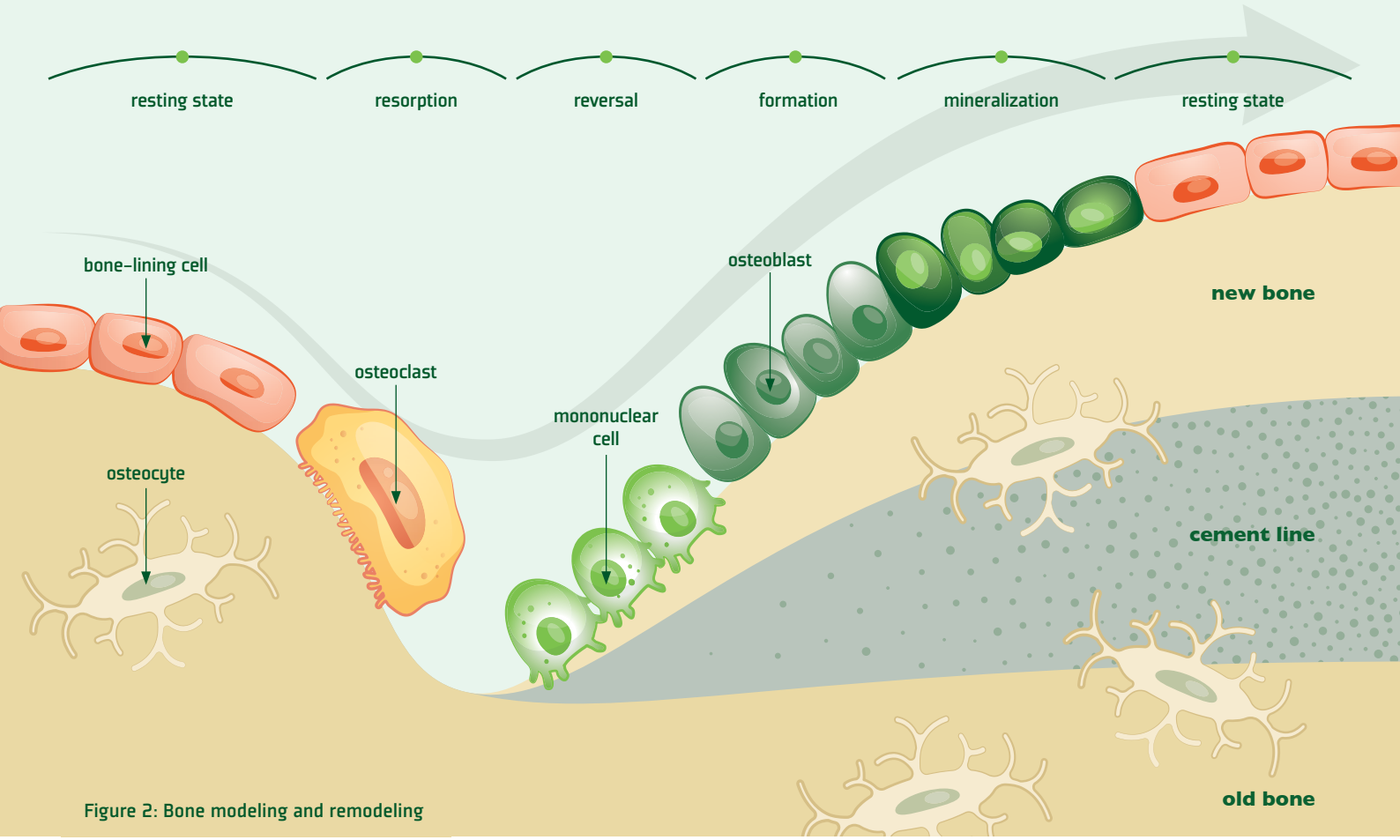
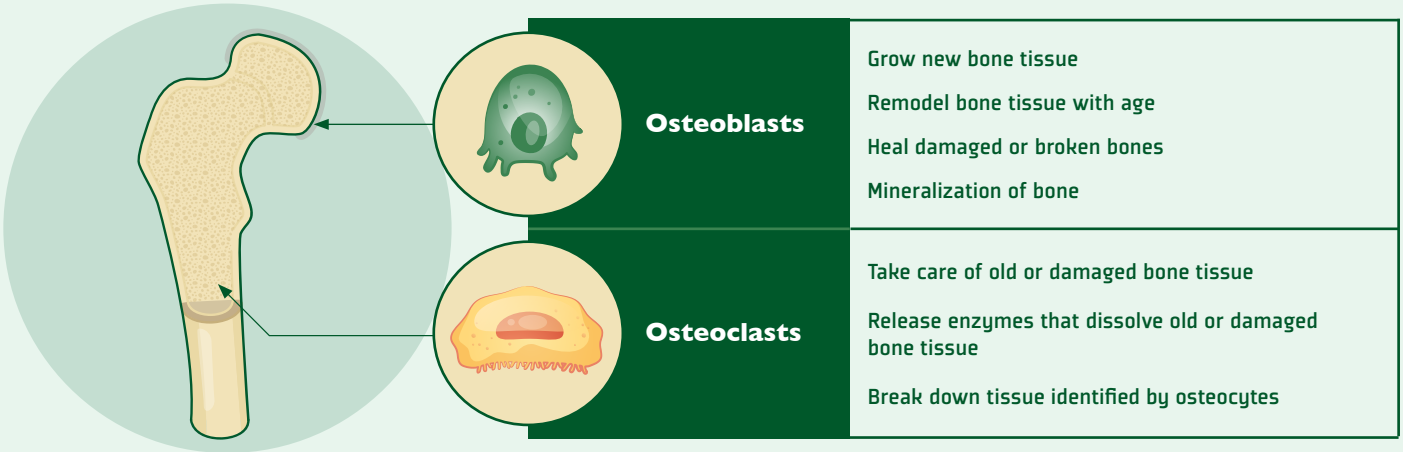


Figure 2: Bone modeling and remodeling

Osteocytes

Osteoctyes are the most common cells found within the bone tissue. They monitor the health of the bone and when stressors are placed on the bone. If the bone tissue becomes damaged, osteocytes are responsible for sending signals to the osteoclasts and osteoblasts, to remove damaged bone tissue and build new bone tissue, respectively.

Osteoblasts and osteoclasts



Osteoblasts are activated by hormones and deposit a bone matrix (collagen, calcium, phosphate and other minerals) onto areas of the bone that either need to grow or be repaired. The bone matrix then hardens to become new healthy bone. Once the new bone tissue has been laid, osteoblasts will either transform into osteocytes, or die. When old or damaged bone tissue is present, osteoclasts release enzymes that dissolve that bone tissue. Osteoclasts will only break down tissue identified by osteocytes.

Primary factors that impact bone remodeling

There are two primary factors that impact how the bone is remodeled and the strength of the bone throughout adulthood:

1 The availability of calcium in the blood

The human body tightly regulates serum calcium levels and will sacrifice bone tissue to maintain calcium homeostasis. Without adequate calcium ingestion, calcium is not available to be deposited into the bone tissue. In youth and early adulthood, if inadequate amounts of dietary calcium are consumed, bone formation may be compromised. In addition, existing bone tissue may be broken down to release stored calcium back into the blood to maintain serum calcium levels. Prolonged breakdown of bone tissue can compromise bone density in both youth and adulthood.

Dietary calcium intake is critical to supporting bone growth during youth and bone maintenance and health during adulthood. Foods and beverages high in calcium include:

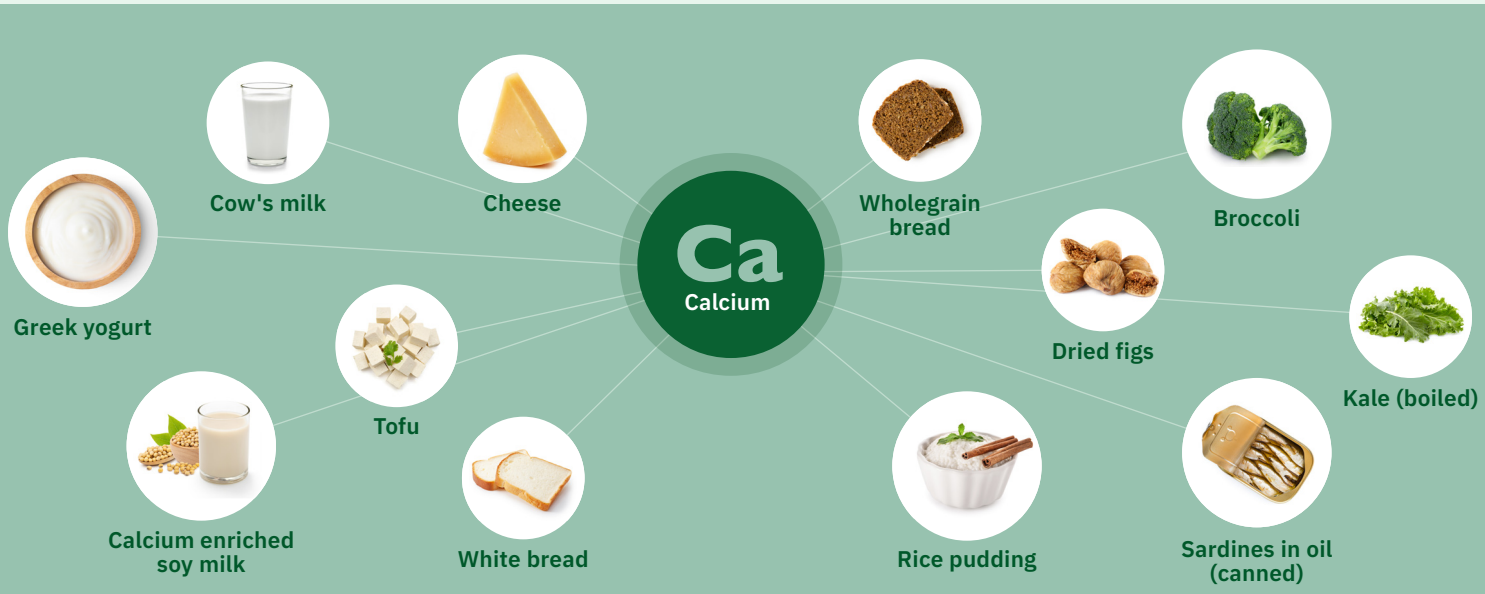


Figure 3: Foods rich in calcium

2 The pull of gravity and muscles on the skeleton

Exercise is classed as weight bearing when the person is on their feet and the skeleton is supporting their body weight. Exercises like walking, running, dancing, as well as sports involving running or jumping (e.g., tennis, soccer, basketball, etc), are all considered weight bearing. The mechanism of weight bearing activity causes muscles and tendons to put stress on the bone tissue. This stimulates bone formation and strengthens bones.

Bone health throughout the lifespan

Bone is a dynamic and active tissue. The greatest amount of growth in bone length and diameter occurs during puberty, until the epiphyseal (growth) plates close (Figure 4). During this period, over 90% of an individual's total bone density is acquired. Bone mass can also be accrued through the third decade of life through a combination of load bearing physical activity and adequate dietary intake. After this point, the focus shifts to the maintenance of bone mineral density.

Osteoporosis, and its pre-cursor osteopenia, are health conditions characterized by low bone mineral density. Osteoporosis is generally considered an aging disease. However if peak bone mineral density is not acquired during puberty, and there is continued inadequate energy and/or micronutrient intake, it is possible for athletes to develop osteopenia and osteoporosis at a younger age. Porous and brittle bones are not compatible with life as a competitive athlete and can cause an early end to promising careers.

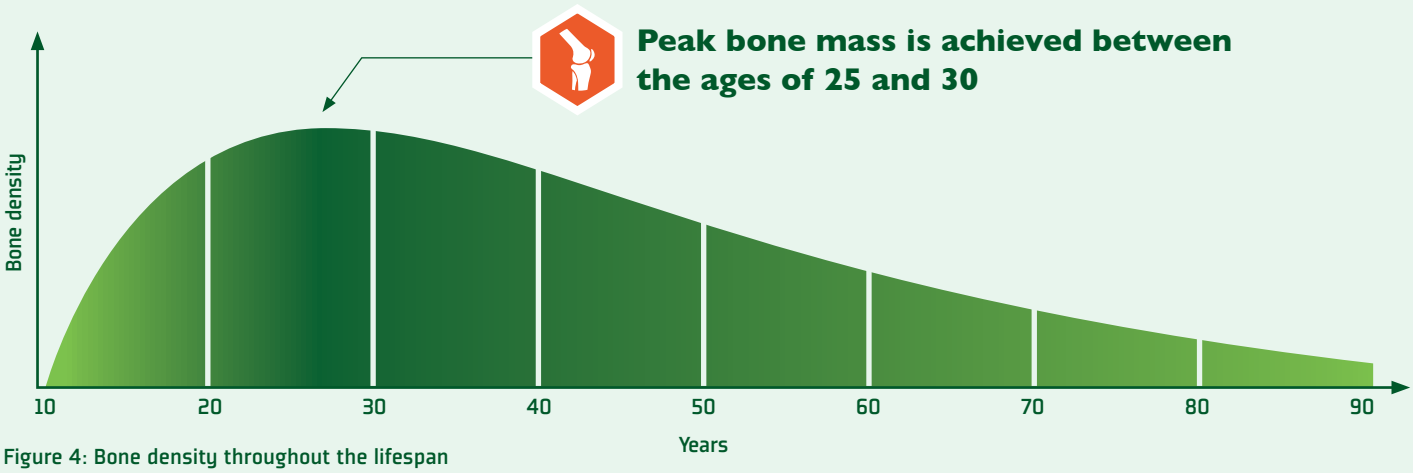


Figure 4: Bone density throughout the lifespan

Critical time points

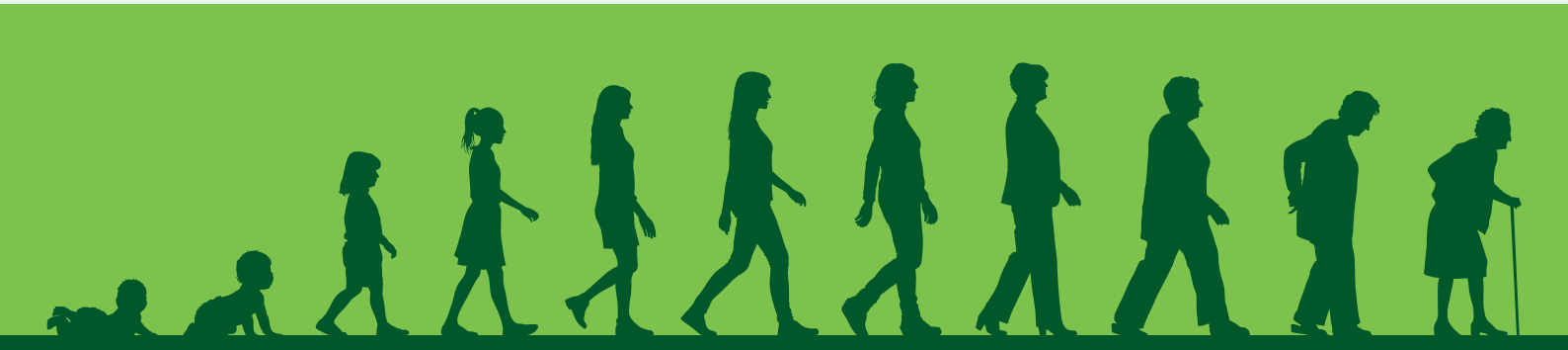
Puberty

Throughout childhood and adolescence, cells called chondrocytes within the epiphysial plates are continuously producing new cartilage. The cartilage will ultimately be replaced by mature osteocytes when the epiphysial plates close. At the same time, modeling and remodeling of existing bone is also occurring. Bone modeling is closely related to the production of sex steroid hormones, particularly estrogen in females.

Menopause

Bone loss with aging is not an unexpected phenomenon, but effort should be made to minimize losses in bone mineral density. In females, estrogen production significantly decreases with the onset of menopause. This decrease, when combined with lack of weight bearing exercise and low intake of dietary calcium, vitamin D and magnesium, can significantly increase the risk of the development of osteopenia or osteoporosis. The risk is even greater if an individual already has weak and porous bones prior to menopause.

As over 90% of bone mineral density is acquired in the first two decades of life, providing adequate calcium to maximize bone density during this time is critical to lifelong bone health.



Nutrition and bone health

Energy balance

Adequate energy intake supports the overall health of bone. When in prolonged energy restriction, disruptions occur within the endocrine system that can ultimately have a negative impact on bone health. See 'Energy Availability' for more information on the impact of energy restriction on bone health.

Protein

Protein plays an important role in the production and action of Insulin-like Growth Factor (IGF-1), which is necessary for bone formation. IGF-1 stimulates the absorption of the bone mineral elements calcium and phosphate in the intestines, as well as the renal tubular reabsorption of phosphate. Without adequate protein intake during puberty, the production and action of IGF-1 are impaired, which can negatively impact bone mineral density.

In older athletes, particularly post-menopause, bone strength is positively correlated with greater dietary protein intake. In addition to bone health, adequate protein intake with aging can also reduce the risk of muscle weakness and loss (sarcopenia).

Micronutrients

There are several micronutrients which are key for bone health. Figure 5 shows dietary sources of each of these micronutrients, and Table 2 discusses these micronutrients in further detail.

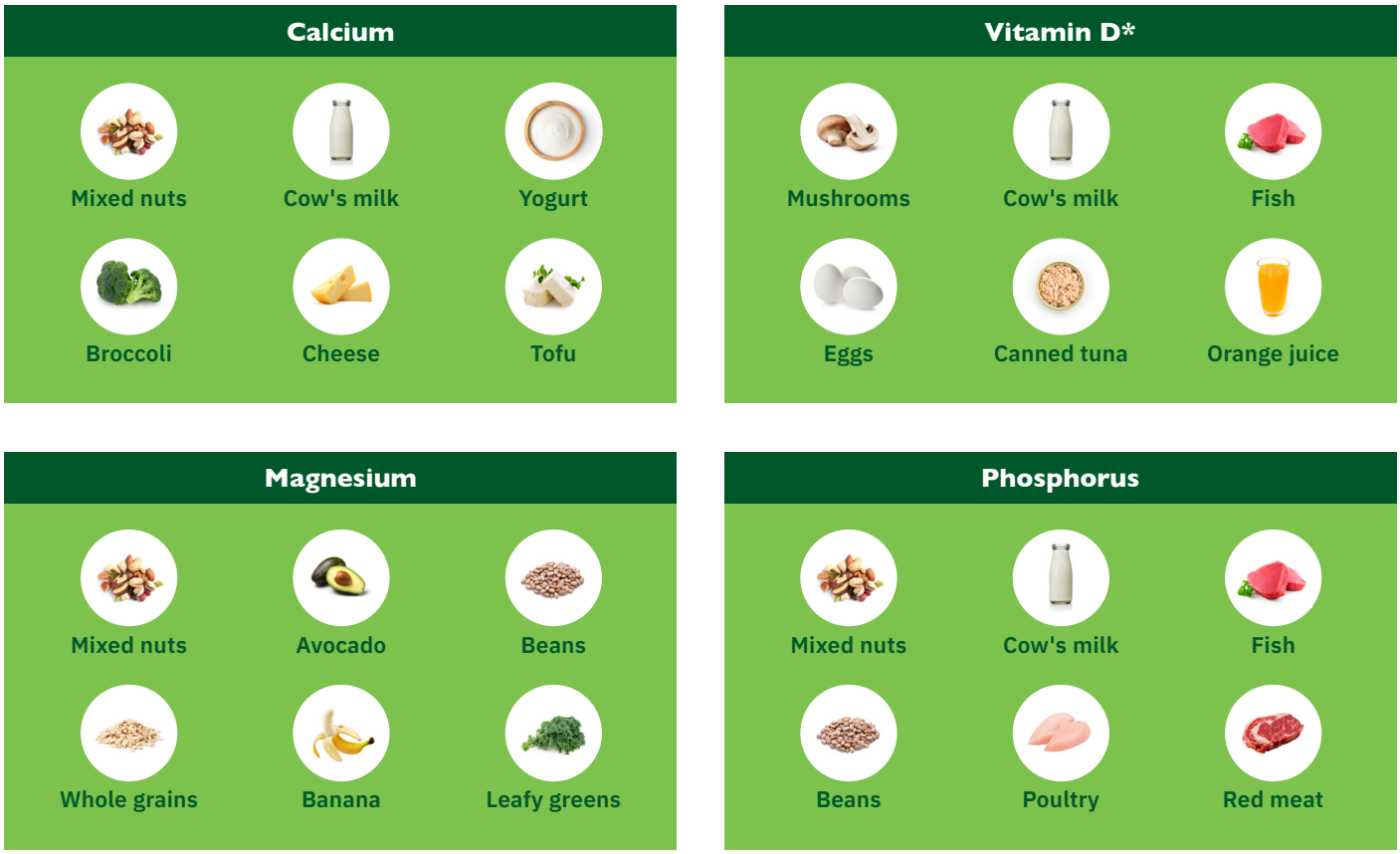


Figure 5: Dietary sources of key micronutrients for bone health

*Due to the limited number of natural sources of vitamin D and limited exposure to UV rays from the sun, supplemental intake of vitamin D3 may be warranted after consulting with a physician. See the vitamin D section of 'Micronutrients' for more detail.

Table 2: Functions of various micronutrients, and consequences of insufficient/excess intakes

	Function	Insufficient intake	Excess intake
20 Ca **Calcium**	Calcium is the primary mineral found in bone tissue. When adequate calcium is consumed during both the development and maintenance phases of bone formation, bone mineral density is maximized and subsequently the integrity of the bone is maintained throughout the lifespan.	When serum calcium falls below a certain level and no exogenous calcium is consumed, the calcium that is stored within the bone can be removed to maintain serum calcium homeostasis. Continuous removal of calcium is detrimental to the integrity of the bone structure if not replaced.	Hypercalcemia (too much calcium in the blood) is most frequently caused by issues with the parathyroid hormone, or other medical conditions. Excess supplemental intake of calcium (>2000 mg/d) can also cause hypercalcemia which, in turn, can cause weakness in the bone or bone pain.
Vitamin D	Vitamin D is a critically important micronutrient for bone health. Vitamin D and its metabolites are a key component to endocrine regulation of serum calcium through the mechanisms of intestinal absorption, stimulating the breakdown of bone tissue and renal absorption of calcium.	Inadequate Vitamin D intake and subsequent Vitamin D deficiency negatively impacts the regulation of calcium, which can result in poor bone health. Other symptoms of Vitamin D deficiency include muscle weakness, muscle aches, fatigue, joint pain, and increased suseptibility to illness.	Toxicity is rare but generally occurs with excessive supplemental intake of Vitamin D. Hypervitaminosis D can result in hypercalcemia in the blood due to disruptions in calcium regulation.
12 Mg **Magnesium**	From an endocrine standpoint, magnesium indirectly impacts bone health because it is an essential co-factor in the activation of Vitamin D (1,25[OH]2D or calcitriol). Consuming adequate amounts of magnesium is necessary in order to achieve the optimal benefits of Vitamin D.	Based on NHANES data, nearly half of all Americans consume less magnesium than recommended. Diagnosing a magnesium deficiency is difficult though since serum magnesium status does not always reflect total body magnesium.	Toxicity generally occurs with excess supplementation of magnesium, or in individuals with renal issues. Excess magnesium intake from food does not pose a risk in healthy individuals because the kidneys eliminate excess amounts in the urine.
15 P **Phosphorus**	Phosphorus is another mineral involved in the mineralization of bone tissue as part of hydroxyapatite. Approximately 85% of phosphorus in the human body is found within the skeleton. It is a necessary mineral for osteoblasts to work and osteocytes to form.	Phosphorus deficiency is rare in adults. According to NHANES data, most Americans consume more than the recommended daily intake for phosphorus.	Excess phosphorus intake may lead to hypocalcemia or low serum calcium due to the affinity of phosphorus for binding to calcium in the digestive tract, reducing calcium absorption and availability for building bone structure. High dietary phosphorus intake may also increase PTH secretion, which in turn can lead to increased bone resorption or breakdown to release calcium into the bloodstream.

Practical suggestions

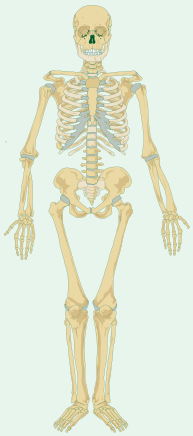
Adequate energy intake can help to minimize the risk of micronutrient deficiencies, particularly when a wide variety of foods are consumed.

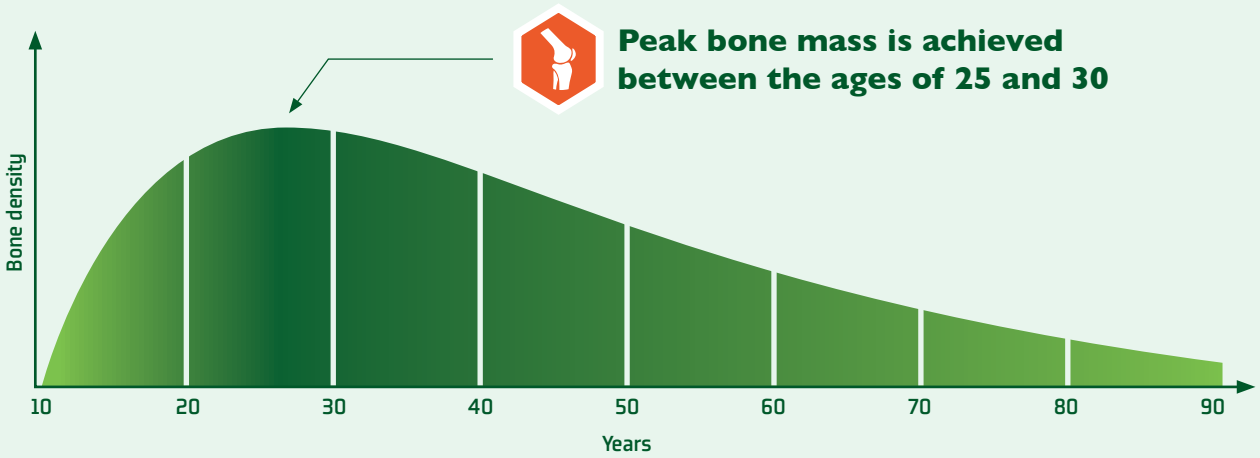
Female athletes should be encouraged to eat regularly throughout the day, between 4-6 meals including multiple food groups at each meal.

Protein intake is also critically important when it comes to developing and maintaining bone mineral density. It is highly recommended to screen female athletes for low energy availability/REDs, particularly those at high risk. This can help to identify athletes who are in need of intervention and education.

BONE HEALTH

Bone health is extremely important for female athletes





Primary factors impacting bone remodelling and strength

Level of calcium in the blood

Dietary calcium intake is critical to supporting bone growth during youth and bone maintenance and health during adulthood

Pull of gravity and muscles on the skeleton

Weight-bearing exercise causes muscles and tendons to put stress on the bone tissue, which stimulates bone formation and strengthens bones

Nutrition and bone health

Energy balance

Adequate energy intake supports the overall health of the bone

Protein

In adults, bone strength is positively correlated with greater dietary protein intake

Calcium

Adequate calcium consumption maximizes bone mineral density

Vitamin D

Key component for endocrine regulation of serum calcium

Magnesium

Adequate magnesium intake is necessary to achieve the optimal benefits of Vitamin D

Phosphorus

Involved in the mineralization of bone tissue, necessary mineral for osteoblasts to work and osteocytes to form

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