Diet-Induced Weight Loss: The Effect of Dietary Protein on Bone

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ARTICLE INFORMATION

Article history:
Accepted 6 August 2013
Available online 30 October 2013

Keywords:
Dietary protein
High-protein diet
Bone
Weight loss
Adults

2212-2672/$36.00
http://dx.doi.org/10.1016/j.jand.2013.08.021

ABSTRACT

High-protein (>30% of energy from protein or >1.2 g/kg/day) and moderately high-protein (22% to 29% of energy from protein or 1.0 to 1.2 g/kg/day) diets are popular for weight loss, but the effect of dietary protein on bone during weight loss is not well understood. Protein may help preserve bone mass during weight loss by stimulating insulin-like growth factor 1, a potent bone anabolism stimulator, and increasing intestinal calcium absorption. Protein-induced acidity is considered to have minimal effect on bone resorption in adults with normal kidney function. Both the quantity and predominant source of protein influence changes in bone with diet-induced weight loss. Higher-protein, high-dairy diets may help attenuate bone loss during weight loss.
J Acad Nutr Diet. 2014;114:72-85.

TWO THIRDS OF US ADULTS ARE CONSIDERED overweight or obese (body mass index ≥25) and it is a serious public health concern.[1] Weight reduction is recommended for overweight and obese adults to reduce the risks of coronary heart disease and type 2 diabetes.[2] However, body weight is directly associated with bone mass and obese adults usually have higher bone mineral density (BMD) and decreased occurrence of osteoporosis.[3] Weight loss, especially via energy restriction, has been observed in numerous studies to be associated with bone loss.[4-6] Therefore, maintenance of BMD after weight loss is extremely important to maintain bone integrity and avoid fracture.

Among weight-loss diets, moderately high-protein (1.0 to 1.2 g protein/kg/day or 22% to 29% of total energy consumed) or high-protein (>1.2 g protein/kg/day or >30% of total energy consumed) intake is recommended and promoted because it may help preserve lean body mass[7-10] and reduce insulin resistance[11] compared with a normal or low-protein intake (at or below the Recommended Dietary Allowance of 0.8 g protein/kg/day). Protein is an important component of bone tissue that by volume contains 50% protein[12] and synthesis of bone structure requires a continuous supply of amino acid precursors.[13] Multiple studies have evaluated the effects of dietary protein on bone under weight stable conditions. Although dietary protein increases urinary calcium excretion,[14-16] it also stimulates intestinal calcium absorption[17] and increases the circulating concentration of insulin-like growth factor 1 (IGF-1).[18-20] Both intervention[21] and observational[22] studies have found that a higher dietary protein intake has beneficial effects on bone and inadequate protein intake is associated with increased risk of fractures.[23] A recent meta-analysis also supports a positive association between protein intake and bone health in weight-stable adults.[24] However, the potential influence of consuming a higher-protein (ie, moderately high and high) diet as part of a weight loss strategy on bone remains unclear and multiple factors could affect the interpretation of results. Although literature on the influences of dietary protein on bone in weight-stable adults provide important scientific and clinically relevant information, caution is warranted before applying findings from these studies to weight loss conditions because weight loss influences bone metabolism and negatively affects bone. The aim of our review is to analyze and evaluate the effects of dietary protein on bone in conjunction with weight loss by overweight and obese adults and to discuss related dietary and experimental factors. It is recognized that exercise has also been shown to affect bone during weight loss, but this topic is beyond the scope of this particular review article.[25] The Figure provides a list of terms, their abbreviations, and their definitions that are used in this review.

Protein intake can be expressed as percent of total energy intake or relative to body weight (grams per kilogram body weight per day). Protein intake in percent total energy can be used to compare protein intake with fat and carbohydrate intakes, which are usually presented as percent total energy. Because protein need is closely related to body/lean mass, protein intake is described more often as grams per kilogram body weight per day. In our review, both percent and grams per kilogram body weight per day are presented when information is available.

We used a traditional model of literature review as opposed to the more systematic approach recommended

Term	Definition
Protein intake	
High	>30% of energy from protein or >1.2 g/kg/d
Moderately high	22%-29% of energy from protein or 1.0-1.2 g/kg/d
Normal	15%-21% of energy from protein or 0.8-1.0 g/kg/d
Low	<15% of energy from protein or ≤0.8 g/kg/d, the Recommended Dietary Allowance
Potential renal acid load (PRAL)	PRAL=[0.49×protein (g)]+[0.037×phosphorus (mg)]−[0.021×potassium (mg)]−[0.02×magnesium (mg)]−[0.013×calcium (mg)][a]
Insulin-like growth factor 1 (IGF-1)	An anabolic factor to stimulate calcium accumulation in bone
Dual-energy x-ray absorptiometry (DXA)	Directly measures bone mineral content (g) and bone area (cm^2)
Bone mineral density (BMD)	BMD (g/cm^2)=BMC (g)/bone area (cm^2)
Bone mineral content (BMC)	The quantity of bone mineral in the body

[a]Remer T, Manz F. Potential renal acid load of foods and its influence on urine pH. *J Am Diet Assoc*. 1995;95(7):791-797.

Figure. Terms used in a review designed to analyze and evaluate the effects of dietary protein on bone in conjunction with weight loss by overweight and obese adults and to discuss related dietary and experimental factors.

by the Academy of Nutrition and Dietetics.[26] This approach was taken because we describe multiple important topics regarding dietary protein, weight loss, and bone, rather than one or two feasibly done for a systematic review. Also, we did not conduct a specific systemic review because the mechanistic data and scientific perspectives imbedded in many publications are not readily or comprehensively obtained and gleaned from the publications based on key words or medical subject heading terms. As such, this article should not be considered a comprehensive review of the topic-specific literature. A PubMed search using key words *protein*, *weight loss*, and *bone* was used to filter literature, followed by a customized search of research article bibliographies.

DIETARY PROTEIN'S EFFECT ON BONE DURING WEIGHT LOSS

Weight reduction is closely associated with bone loss. Specifically, a 10% weight loss can lead to 0% to 2% BMD loss in adults.[27,28] Multiple studies[29-36] have assessed the ways dietary protein affects bone during weight loss. The Table provides a summary of literature addressing the relation between dietary protein and bone health during weight loss. Listed studies are clinical trials targeting weight loss via energy restriction and reported bone-related parameters (ie, BMD, bone mineral content, bone mass, and bone resorption/formation markers). Protein intake is described as percent total energy intake and relative to body weight (grams per kilogram body weight per day). BMD reductions among the nine studies presented range from 0% to −3.3%. Findings of the effect of dietary protein on bone are not consistent. Some studies[32,33,36] found high-protein diets help attenuate BMD loss or bone markers, whereas others found no effect or a detrimental effect of dietary protein on bone during energy-restriction-induced weight loss.[29-31,34,35] Different study designs, including the length of intervention, predominant protein sources of the diet, and calcium content, as well as discrepancies in data reporting, can all lead to inconsistency of the results. The following sections will discuss each of these factors and evaluate available evidence in more detail.

SULFUR-CONTAINING PROTEIN AND ACID LOAD

Bone contains 99% of the calcium in the body and serves as a buffer in response to acid stress to release calcium and magnesium.[37] A prolonged exposure to an acidic environment could lead to bone resorption and decreased bone mass. Dietary protein is a source of metabolic acid and is reported to decrease urinary pH levels.[13] Protein high in methionine and cysteine is believed to be more harmful because these sulfur-containing amino acids are substrates for sulfuric acid synthesis in the body.[38] Animal-based protein is reported to be more detrimental than plant-based protein in some studies[39,40] because of its higher sulfur content, but not others.[22] This could partially be due to the various contents of methionine and cysteine from different protein sources that cannot be simply categorized as animal vs plant protein. Wheat protein, for example, has high sulfur content and could contribute to increased acid load even though it is a plant-based protein source. Some researchers argue that sulfur-containing proteins consumed in the diet cannot lead to metabolic acidosis because the acid yielded is not strong enough for a prolonged effect[41] and would not require bone tissue mobilization to release buffer equivalents such as calcium and magnesium.[41,42] However, when kidney function, including regulating acid/base homeostasis, is impaired (ie, with aging), a dietary acid load may have a negative effect on calcium balance[39,43] because the kidneys are no longer capable of filtering acid efficiently. Thus, a healthy adult consuming protein from the diet should not be at risk for bone loss due to increased acidity.

Evidence from weight-stable subjects is also inconclusive. A 7-year follow-up of postmenopausal women[39] showed that a higher ratio of animal/vegetable protein intake was associated with a greater risk of hip fracture, but not low BMD. In the Nurses' Health Study,[40] higher animal protein consumption was associated with an increased risk of forearm fracture, but not hip fracture. Moreover, women who consumed five or more servings of beef, pork, or lamb per week had an increased forearm fracture risk than women who consumed less than one serving of red meat per week.[40] On the other