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# Dietary Patterns and Pediatric Bone

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## Abstract

**Purpose of Review** Much of what we know about dietary patterns (DPs) and bone is derived from cross-sectional studies in adults. Given, establishing healthy bones during childhood serves as a blueprint for adult bone, it is important to better understand the role of DPs on pediatric bone. The purpose of this review is to determine if DPs influence bone strength in children.

**Recent Findings** The majority of studies investigating the role of DPs on pediatric bone are cross-sectional in design and examine data-derived "a posterori" DPs. Overall, the DPs characterized by high intakes of fruits and vegetables demonstrated positive effects on pediatric bone.

**Summary** Results from both "a posteriori" and "a priori" DPs approaches in children suggests that DPs dominated by the intake of fruits and vegetables might be beneficial for pediatric bone. Future studies may consider "a priori" DPs interventions to better understand relationship between DPs and pediatric bone.

**Keywords** Bone · Pediatric bone · Dietary patterns · Diet

## Introduction

The association between diet and health is not a new concept. In 400 BC, Hippocrates stated, "Let thy food be thy medicine and medicine be thy food." Beginning in the early to mid-twentieth century, the focus of nutrition was on the discovery of individual nutrients and their associations with deficiency diseases. Towards the later part of the twentieth century and into the twenty-first century, there was a shift to studying the role of individual nutrients, and the diet as a whole in disease prevention and treatment. Given, nutrients are not consumed in isolation, but rather, packaged and consumed together, which may have synergistic and cumulative effects, it has been hypothesized that dietary patterns may be more robust in producing positive or negative effects on health. By describing and calculating dietary intake as dietary patterns, one is able to study the entire diet rather than individual nutrients or foods [1, 2]. The aim of this paper is to determine if dietary patterns influence bone growth in children. In order to answer this question, specific methods that are used to describe dietary patterns (i.e., the "a posterori" and "a priori" approaches) will first be addressed and then we will explore common dietary patterns associated with bone health and their influences on pediatric bone.

There are two main methods to describe a dietary pattern: (1) the data-derived or "a posteriori" dietary pattern approach and; (2) the "a priori" dietary pattern approach. The "a posteriori" approach uses statistical methods such as factor analysis, cluster analysis, and reduced rank regression to derive dietary patterns from collected data [3–5], while the "a priori" dietary pattern approach uses dietary indexes created on the basis of existing nutritional knowledge, and typically assesses compliance with dietary guidelines and recommendations [3]. Both of these methods to define dietary patterns measure adherence by a scoring algorithm [3–5].

The most common data-derived, "a posteriori" dietary pattern approach is factor analysis, which relies on subjective decisions during analysis (e.g., definition, number of food groups entered, and number of factors to retain) and therefore, may lead to variations in pattern definitions across studies [6–8]. Cluster analysis determines dietary patterns through grouping individuals into clusters. For example, participants may be clustered based on the consumption of high-fat foods,

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high protein foods, or dairy products. These clusters have similar within-cluster and different between-cluster dietary intakes among individuals [3, 5]. Factor analysis and cluster analysis derive dietary patterns without accounting for disease risk or intermediate health outcomes. To account for this limitation, the reduced rank regression analysis determines the intercorrelation among dietary components by maximizing the explained variance in the selected intermediate variables, which could include health outcomes (e.g., bone mineral content [BMC] or areal bone mineral density [aBMD], or nutrient intake) [4]. Food groups and loading factors derived from the "a posteriori" method may not be identical across studies making it difficult to reproduce and compare the dietary patterns findings across studies.

The "a priori" dietary patterns approach generally measures compliance with dietary guidelines and recommendations by scoring algorithms [3, 5, 9]. The final score measures the adherence to a specific dietary recommendation but does not assess the overall quality of the diet. For example, it does not account for higher energy intake, nutritional adequacy, socioeconomic status, and income level. While the "a posteriori" dietary pattern approach uses statistical methods to determine dietary patterns from existing data, the "a priori" dietary patterns approach uses past knowledge to select diets of interest (i.e., related to a health outcome) for inclusion in the study [3, 4].

This paper will focus on the data-derived "a posteriori" dietary patterns and the "a priori" dietary patterns, the Mediterranean diet (MD), the Dietary Approaches to Stop Hypertension (DASH) diet, the Healthy Eating Index (HEI), and the Western diet. These "a priori" dietary patterns are commonly assessed in relation to bone outcomes, which is why they were included in this review [10]. The MD is an eating pattern based on the traditional cuisine of countries bordering the Mediterranean Sea [11]. Characteristics of the MD include high intakes of fruits, vegetables, whole grains, beans, nuts and seeds, and healthy fats [11]. The DASH diet originated in the early 1990s. In 1992, the National Institute of Health started funding research projects investigating whether specific dietary interventions (i.e., DASH diet) were useful in treating hypertension [5]. The DASH diet promotes increased consumption of fruits and vegetables, lean meats and dairy products in the diet. It also promotes reducing sodium intake to approximately 2300 mg per day for healthy individuals and including foods that are rich in the minerals potassium, magnesium, and calcium [12]. The HEI is a tool to evaluate the extent to which North American's are following the Dietary Guidelines for Americas (DGAs) recommendations. The HEI has been updated twice since 1995 and uses a scoring system to evaluate a set of foods. Scores range from 0 to 100 and the score is made up of 13 components that reflect the different food groups and key recommendations in the DGAs [13]. The Western diet, sometimes referred to as the standard North American diet, is a dietary pattern characterized by high intakes of red and processed meats, pre-packaged foods, butter, fried foods, high-fat dairy products, refined grains, potatoes, corn, and sugar-sweetened beverages [14]. The increasing prevalence of metabolic diseases (e.g., obesity and type 2 diabetes) in countries adapting a Westernized lifestyle has in part been attributed to increased intakes of foods commonly consumed in the Western diet [15]. For example, a diet characterized by high consumption of rye, potatoes, butter, sausage, milk, and coffee was associated with increased cardiovascular disease risk in men [16].

Over the last several decades, considerable evidence supports the hypothesis that dietary patterns play a relevant role in the development and progression of diseases. For example, in two large cohort adult studies, adherence to the MD was found to significantly modify the cardiovascular risk profile [17, 18]. Similarly, the DASH dietary pattern has been shown to reduce both systolic and diastolic blood pressure [19], reduce the risk of heart failure [20], improve insulin sensitivity and reduce the risk of type 2 diabetes [21], cardiovascular diseases, and strokes [22] in adults. Diets that score high on the HEI are associated with a significant decrease in the risk of all-cause mortality [23], cardiovascular disease [24], cancer [25], and type 2 diabetes [26]. Lastly, it is well documented that the Western diet is associated with increased incidence of coronary heart disease [27], cardiovascular disease [20, 22], and type 2 diabetes [28], among others. While these diseases are most common in adults, children and adolescents are increasingly being diagnosed with these chronic conditions [29, 30]. This is worrisome given many chronic diseases track from childhood into adulthood, putting these children at an increased risk for health complications later in life [16, 31, 32]. More recently, there has been increased interest in the role of chronic metabolic diseases on bone health. For example, obesity is thought to have detrimental effects on bone health outcomes in both children and adults [33]. Although the mechanisms are not well understood, obesity is an inflammatory state and circulating levels of pro-inflammatory cytokines may promote increased osteoclast activity and bone resorption [33]. Moreover, a high-fat diet which is commonly seen in obese individuals may result in reduced bone mineral density and bone quality; however, because fat generally has a positive effect on calcium absorption, we suggest other mechanisms are affecting the poor quality bone seen in obesity [33, 34].

Although the focus of dietary patterns and health research has primarily investigated metabolic diseases such as type 2 diabetes and cardiovascular diseases, there has been an increased interest in the influence of dietary patterns on bone health. Osteoporosis is a public health burden due to its high prevalence and significant contribution to high morbidity and mortality rates [35]. Globally, osteoporosis influences approximately 33% of women and 20% of men over the age of 50. Nutrition is an important modifiable factor influencing bone strength [36]. The majority of evidence supporting the role of nutrition on bone has focused on individual nutrients, particularly calcium, vitamin D, and the macronutrient protein [37–42]. A limited number of studies have focused on individual food items such as milk, food groups like dairy foods, or dietary patterns such as the Mediterranean diet. The research investigating the role of dietary patterns on bone health has primarily targeted adult populations, with little focus on child and adolescent bone.

## Dietary Patterns and Adult Bone

Much of what we know about dietary patterns and bone is derived from cross-sectional studies in adults, as there is an overall paucity of randomized controlled trials and prospective longitudinal studies. In a recent scoping review, adults that consumed a "Prudent/Healthy" (comparable to MD and DASH dietary patterns) dietary pattern had a decreased risk of low total body aBMD [10]. Moreover, older men that consumed the "Prudent/Healthy" dietary pattern had a reduced risk for fracture. Benetou et al., examined 188,795 men and women, and found increased adherence to the MD pattern was associated with a 7% decrease in hip fracture incidence [43]. This association was more evident among men and somewhat stronger among older individuals [43]. In a similar study, greater adherence to a MD dietary pattern was not associated with decreased risk of fractures in older individuals [44]. The study populations differed by age, size, and geographical location, which makes it difficult to compare the findings across studies. In an ancillary study from the DASH-Sodium trial, a randomized feeding trial conducted among participants at two clinical sites, participants consuming the DASH dietary pattern had significantly reduced bone turnover, as indicated by decreased serum osteocalcin and C-terminal telopeptide of type I collagen, compared to a control diet [45]. If this reduction in bone turnover is sustained, it may have positive effects on bone mineral status and ultimately reduce the risk of osteoporosis. In a case-control study of 726 aged 55–80 years, high HEI scores were related to reduced risk for hip fracture [46]. Similarly, adherence to the alternate HEI, which was derived from the original HEI and considers the quality of the diet, was associated with decreased risk for hip fracture in men and women ages 45–74 years [47] and 55–80 years [46]. To date, no studies have investigated the role of the Western "a priori" dietary pattern on adult bone. In "a posteriori" studies, dietary patterns similar to the Western dietary pattern have been associated with increased risk for low aBMD in adults older than 50 years and increased fracture risk [10].

## Pediatric Bone Development

Establishing healthy bones during childhood serves as a blueprint for skeletal health in adulthood. One of the main determinants of bone strength and osteoporotic fractures is low bone mass. Low bone mass can be attributed to a failure to achieve optimal peak bone mass during childhood or the inability to slow bone loss in adulthood [48]. Adolescence is a critical period of bone development with 90% of adult bone mass obtained by the age of 18 [49] (Fig. 1). The attainment of the majority of adult bone mass in adolescence is important given BMD tracks from childhood into adulthood [50]. For example, in a prospective study of dual-energy x-ray absorptiometry (DXA–derived bone outcomes, Yang et al. determined that aBMD at the spine, hip, and total body tracks from age 8 to age 25 in males and females [51]. Thus, maximizing the amount of peak bone mass gained during childhood is an important strategy aimed at preventing low bone mass and osteoporosis in adulthood. Additionally, during childhood and adolescence dynamic changes in the size and shape of the bone occurs, and these changes can be modified by factors including nutrition and physical activity.

## Dietary Patterns and Childhood Bone

There is limited research investigating the role of dietary patterns and childhood bone with a majority of the studies being cross-sectional in design and investigating "a posteriori" dietary patterns. A recent systematic review and meta-analysis examining the role of "a posteriori" derived dietary patterns found that a "Prudent/Healthy" dietary pattern may decrease the risk of low total body aBMD among children and adolescents [10]. In this systematic review and meta-analysis, dietary patterns that showed significant and beneficial effects on aBMD or BMC were primarily characterized by high intakes of vegetables, fruits, low-fat milk and dairy products, whole grains, fish, beans, and nuts [52–55], as well as nutrients, such as calcium found in foods [53]. These dietary patterns were labeled as "Dairy and whole grains" [52], "Calcium foods" [53], and "Milk and cereal" [54]. Woseje et al. investigated the prospective role of "a posteriori" dietary patterns on dual-energy x-ray absorptiometry derived aBMD [56]. A dietary pattern characterized by high intakes of dark-green and deep yellow vegetables was related to high bone mass and low-fat mass, while a diet characterized by a high intake of fried foods was related to high-fat mass and low bone mass [53]. The dietary pattern characterized by a high intake of dark-green and dark yellow vegetables explained 11.4–18.1% of the variation in bone mass and the dietary pattern characterized by high-processed meat intake explained 3.9–5.8% of the variation in bone mass over the 4-year period [56]. In a similar prospective study, a vegetarian-style dietary pattern, characterized by increased intakes of dark-green vegetables, eggs, non-refined grains, 100% fruit juice, legumes, nuts and seeds, added fats, fruits, and low-fat milk during adolescents was positively associated with total body BMC and aBMD [57].

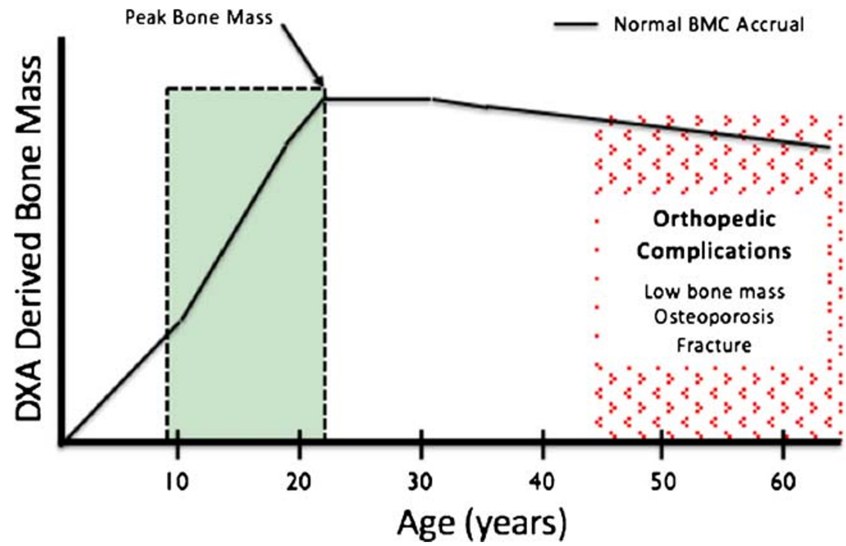


**Fig. 1** Peak bone mass gains during childhood [42]

Participants who had higher adherence to the vegetarian-style diet during adolescents also had higher total body aBMD and BMC, as well as, femoral neck aBMD and BMC during young adulthood, average 15 years later [57]. Lastly, in Chinese children, adherence to a calcium food pattern, characterized by high intakes of milk and dairy products, beans and bean products, fresh fruit and eggs, and a Chinese tradition pattern characterized by high intakes of grains, fresh vegetables, and fruits, and pork was associated with decreased risk for osteopenia and osteoporosis as determined by an ultrasound bone densitometer [53]. The Western style diet is characterized by high intakes of fat, saturated and trans fats, and sodium. These nutrients are all considered pro-inflammatory. The Dietary Inflammatory Index® (DII) was developed to assess the overall quality of the diet on a continuum from maximally anti-inflammatory to maximally pro-inflammatory [58]. Coheley et al. [59] examined the role of the DII on radius and tibia cortical bone outcomes in healthy children. The DII score was negatively associated with tibia trabecular area, periosteal circumference, endosteal circumference and strength strain index and radius total area, periosteal circumference, and strength strain index [59]. Interestingly, these relationships did not persist after controlling for the covariates, stage of sexual maturation, sex, race, muscle cross-sectional area (tibia and radius), and height [59]. In a recent systematic review and meta-analysis in adults, the authors concluded that even after controlling for relevant covariates, diets characterized by high pro-inflammatory components may lead to low aBMD of the lumbar spine and total hip and an increased risk for osteoporosis and fractures [60]. The negative effect of DII on adult bone, but not childhood bone, may be attributed to differences in the covariates included in the statistical analyses. For example, some of the adult studies controlled for the covariates alcohol intake, smoking status, and personal income, which may not be relevant in children [60]. Additionally, the negative effect of the pro-inflammatory DII score on adult bone, but not childhood bone, may be due to longer duration exposure to the pro-inflammatory diet; however, this is unknown.

To our knowledge, there are only 2 published studies investigating the role of "a priori" dietary patterns and pediatric bone health outcomes (Table 1). In a homogenous sample of boys and girls between 13 and 17 years of age, there were no significant differences in annual variation of distal radius aBMD, by adherence to the "a priori" dietary patterns, MD and DASH [61]. In boys there, linear trend towards increased distal radius aBMD at 13 years with increased adherence to the MD pattern, but the trend was non-significant [61]. The authors did not assess how long participants were consuming the respective dietary patterns, which may have attributed to the non-significant findings. Additionally, the method to determine usual diet intake was food frequency questionnaires, and as with any method to determine dietary intake, under-reporting of intake is possible [63–66]. The authors did not assess biological age, pubertal maturation, or physical activity, all of which impact bone development during growth. In a 28-day nutrition intervention in adolescent boys ages 11 to 14 years, adherence to a Mediterranean-based dietary pattern increased the urinary bone resorption biomarker urine deoxypyridinoline and improved calcium absorption [62]. There are currently no published studies investigating the role of the HEI on pediatric bone. Similarly, to our knowledge, there are no studies investigating the role of the Western diet "a priori" on pediatric bone outcomes. This is important given the potential detrimental effects of the Western diet on bone and the fact that dietary pattern intakes during childhood are thought to track into adulthood [67].

**Table 1** Characteristics of "a priori studies" pediatric studies

| Reference | Objectives and study design | Population description | N | Results |
|---|---|---|---|---|
| Monjardino et al., 2014 [61] | The objective was to quantify the associations between forearm BMD in early and late adolescence and adherence to a priori defined dietary patterns in early adolescence, using the Mediterranean Diet Quality Index for children and adolescence (KIDMED) and DASH diet index. Dietary intake was measured by Food Frequency Questionnaires. Participants were grouped into tertiles of intakes. Forearm aBMD was measured at the distal radius of the non-dominant forearm by DXA. | Sex: males and females<br>Age: 13–17 years<br>Race: no specified<br>Location: Porto, Portugal<br>Year(s): 2003/2004 and 2007/2008 school years | 1180 (474 males) | In girls (13 years old)<br>MD pattern: 1st tertile ($n = 247$), 2nd tertile ($n = 232$), 3rd tertile ($n = 194$), *P*; DASH pattern: 1st tertile ($n = 272$), 2nd tertile ($n = 204$), 3rd tertile ($n = 197$), *P*<br>BL aBMD: 0.360 (0.059), 0.361 (0.055), 0.361 (0.060), .996; 0.359 (0.059), 0.361 (0.057), 0.362 (0.056), .811<br>F/U aBMD: 0.431 (0.052), 0.437 (0.051), 0.437 (0.053), .405; 0.434 (0.056), 0.438 (0.050), 0.434 (0.050), .720<br>In boys (13 years)<br>BL aBMD: 0.338 (0.047), 0.347 (0.052), 0.342 (0.051), .132; 0.342 (0.051), 0.344 (0.052), 0.346 (0.048), .720<br>F/U aBMD: 0.450 (0.074), 0.448 (0.075), 0.458 (0.076), .510; 0.455 (0.074), 0.452 (0.079), 0.448 (0.072), .679<br>All values mean (SD); *aBMD*, areal bone mineral density at the forearm; *MD*, Mediterranean diet; *DASH*, Dietary Approaches to Stop Hypertension; *BL*, baseline; *FU*, follow-up |
| Seiquer et al., 2008 [62] | The objective was to determine whether a 28-day nutrition intervention, in which an intervention Mediterranean-type diet was consumed, influences markers of calcium metabolism (serum calcium, parathyroid hormone and total alkaline phosphatase) and bone resorption (urine deoxypyridinoline). | Sex: males<br>Age: 11–14 years<br>Location: not specified<br>Years: not specified | 20 | • Consuming a Mediterranean-type diet increased calcium retention (~ 80%, $p \le .01$) and decreased urinary calcium excretion (~ 40%, $p = .01$) compared to a general diet (basal diet).<br>• A higher rate of bone turnover via the bone turnover marker urine deoxypiridinoline was noted after consuming the Mediterranean-style diet |

## Summary and Conclusions

The majority of studies investigating the role of dietary patterns on pediatric bone are cross-sectional in design and examine the data-derived “a posterori” patterns. Overall, the “a posterori” dietary patterns characterized by high intakes of fruits and vegetables, low-fat milk and dairy products, whole grains, fish, beans, and nuts were associated with positive effects on DXA-derived bone outcomes. There were only 2 studies investigating the role of the “a priori” dietary patterns and bone. One study found a linear trend towards increased radius aBMD with increased adherence to the MD pattern, but the trend was non-significant [55]. Another study found adherence to a Mediterranean-based dietary pattern increased the urinary bone resorption biomarker urine deoxypyridinoline and improved calcium absorption [60].

Results from both “a posteriori” and “a priori” dietary approaches in adults suggests that dietary patterns dominated by the intake of fruits and vegetables, whole grains, poultry and fish, nuts and legumes, and low-fat dairy products, which closely resemble the MD and DASH dietary patterns, are most beneficial for preventing bone loss. Adherences to similar “a posteriori” dietary patterns in children are thought to increase BMD overtime [49, 50, 52, 53, 67] more than dietary patterns that resemble the Western diet [59]. The data-derived dietary patterns are difficult to reproduce and compare across studies. This may partly be explained by the fact the data-derived methods rely on reported dietary intakes and dietary intakes differ by race, gender, population, etc., making it difficult to compare findings. Findings from the “a priori” dietary pattern studies on pediatric bone are difficult to compare given the different outcome measures and dietary patterns of interest. One of the main limitations of the “a priori” dietary patterns approach is related to the use of dietary guidelines that generally are not disease specific and the adherence to them may reduce the risk of some diseases, but not all [68]. These dietary patterns are primarily based on promoting overall health status or preventing chronic diseases, rather than specifically improving bone health. Despite this, overall “a priori” dietary pattern methods are more comparable across studies than the data-derived “a posteriori” methods [3–5, 9]. Another limitation for the “a priori” and “a posteori” dietary patterns approach is that the majority of the research using these methods are cross-sectional in design and assess current dietary intakes and not historical dietary intake, which makes it difficult to assess long-term exposure to dietary patterns. It may be that adults have more years of exposure to certain dietary patterns, which is why there is an effect on adult bone versus childhood bone. Alternatively, the benefits of specific dietary patterns on bone may not be due to the length of time exposed, but the timing of the exposure. Exposure to dietary patterns during periods of bone modeling and rapid growth in children likely differs from the less responsive period of bone remodeling and bone maintenance in adulthood.

Although findings from long-term “a priori” randomized controlled dietary patterns studies and prospective studies would provide insightful information regarding the relationship between dietary patterns and pediatric bone, these studies are generally not realistic and expensive. Future intervention studies may consider incorporating foods commonly found in the MD and DASH into children’s diets to determine if there is an effect on bone. The incorporation of food products would allow the child’s diet to not be completely altered which may aid in adherence. Pilot studies in children may consider a short-term dietary patterns intervention to assess the effect of the diet on serum bone biomarkers before conducting a long-term feeding trial.

## Compliance with Ethical Standards

**Conflict of Interest** I, Lauren Coheley, declare no conflicts of interest.

**Human and Animal Rights and Informed Consent** This article does not contain any studies with human or animal subjects performed by any of the authors.

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