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Nutrition and osteoporosis prevention for the orthopaedic surgeon: a wholefoods approach

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- Osteoporosis is a prevalent and debilitating condition with no signs of subsiding. Rising numbers of people consuming nutrient-poor diets coupled with ageing populations and sedentary lifestyles appear to be the main drivers behind this.
- While the nutrients calcium and vitamin D have received most attention, there is growing evidence that wholefoods and other micronutrients have roles to play in primary and potentially secondary osteoporosis prevention.
- Until recently, calcium and vitamin D were regarded as the main nutrients essential to bone health but now there are emerging roles for iron, copper and selenium, among others.
- Fruit and vegetables are still not being eaten in adequate amounts and yet contain micronutrients and phytochemicals useful for bone remodelling (bone formation and resorption) and are essential for reducing inflammation and oxidative stress.
- There is emerging evidence that dried fruits, such as prunes, provide significant amounts of vitamin K, manganese, boron, copper and potassium which could help to support bone health.
- Just 50 g of prunes daily have been found to reduce bone resorption after six months when eaten by osteopaenic, postmenopausal women.
- Dairy foods have an important role in bone health. Carbonated drinks should not replace milk in the diet.
- A balanced diet containing food groups and nutrients needed for bone health across the whole lifecycle may help to prevent osteoporosis.
- Greater efforts are needed to employ preventative strategies which involve dietary and physical activity modifications, if the current situation is to improve.

Keywords: osteoporosis; preventative nutrition; diet; wholefoods; nutrients; bone health

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Introduction

Osteoporosis is a silent but progressive disease affecting the density and quality of bone while greatly increasing fracture risk.[1] Globally, around one in three women and one in five men are at risk of an osteoporotic fracture, with the most common fractures being at the hip, spine or wrist.[1] The pathogenesis of osteoporosis is multi-faceted, consisting of intricate interplay between physiological processes, including hormonal status, along with genetic and environmental factors.[2] That said, the condition is regarded as being partly preventable by means of suitable nutrition and adequate mechanical influences (physical activity).[3]

Worldwide, it has been estimated that around two billion people have diets inadequate in micronutrients. This, coupled with increasing life expectancies, means that the later years of life are being hampered by partly preventable health issues, including osteoporosis.[4,5] From an economic point of view, rates of disability due to osteoporosis in Europe are greater than that caused by cancers (excluding lung cancer).[6] For orthopaedic surgeons, the treatment of fractures has been the traditional way forward.[7] However, the emergence of screening techniques such as bone densitometry coupled with the growing evidence base in nutritional studies now means that preventative measures can be effective and should be given greater prominence within the profession.[7]

It should be considered that peak bone mass, the point where optimal bone mass and strength is achieved, occurs at the end of the growth period (typically between 16 and 25 years).[8] Equally, the menopausal transition leads to increased bone resorption and disruption of bone micro-architecture[5] with loss of oestrogen, a major regulator of bone metabolism, contributing to this.[9] Consequently, these appear to be opportune periods to tailor modifiable factors affecting bone density and quality, including nutritional prevention.

Previously, there has been a general tendency to focus on individual nutrients, or supplements, rather than a

'whole diet' approach. It is now well accepted that a healthy diet can help to prevent non-communicable diseases, such as osteoporosis, with functional components of food having a key role to play in this.[10] For example, phytonutrients (plant nutrients) are thought to exhibit specific biological activities that help to support human health, including bone health.[11]

The present paper aims to develop knowledge about the role of nutrition in osteoporosis prevention; first, by reviewing randomised controlled trials (RCTs) related to key food groups, and second, by evaluating authorised health claims related to bone health.

Methods

First, a PubMed search for English-language, peer-reviewed, human RCTs was undertaken. Studies published between January 2000 and September 2016 investigating the impact of wholefoods on bone health were considered (Table 1).

To assess the evidence related to wholefoods, the search terms included "fruit", "vegetables", "dairy/milk", "eggs/fish/meat", "legumes/beans/pulses", "dried fruit", "beverages" and "sodium" combined with "bone health" and "osteoporosis". Reference lists of reports and suitable papers were also searched to ensure that relevant studies were located. Papers were included if they investigated associations between the named food groups and suitable markers of bone health.

Secondly, as supplement use can also affect bone health, a PubMed search was conducted to identify 'meta-analytical' papers collating the science in this area (Table 2).

Thirdly, a review of authorised European Food Standards Agency nutrient function health claims related to 'bone health' was undertaken (Table 3).

Results

Fruit and vegetables

Sufficient intakes of potassium-rich foods, such as fruits and vegetables are thought to improve indices of bone health. Possible mechanisms include potential roles in acid-base balance or via the dietary components within these.[12] The acid-base hypothesis proposes that foods which increase urinary acid excretion are deleterious for the skeleton while foods generating neutral or alkaline balance may favour bone growth and prevent bone loss.[13] Vegetables, in particular, providing magnesium and potassium may increase the dietary alkaline load.[14] Four RCTs were identified studying inter-relationships between fruit and/or vegetable intakes and bone health.

In one RCT, 50 healthy postmenopausal women aged 50 to 70 years randomised to eat more than nine servings of specific vegetables/herbs/fruit with bone resorption-inhibiting properties (Scarborough Fair Diet) had positive changes in markers of bone health after three months. In particular, positive changes in calcium conservation were seen compared with baseline along with significant reductions in the bone turnover marker P1NP and the bone resorptive marker CTX in women with osteopaenia compared with those with normal bone mineral density (BMD) within the group of treated women, without intergroup differences. The diet included eating prunes, citrus fruit, green leafy vegetables and a culinary serving of herbs.[15]

A much larger study (n = 48835) conducted on postmenopausal women aged 50 to 79 years found that over a period of 8.1 years a low-fat, five or more servings of fruit and vegetables and grain-based dietary intervention reduced the risk of multiple falls and marginally lowered hip BMD but did not alter fracture risk. However, it should be noted that dietary modifications made in this trial were originally designed to focus on breast cancer and cardiovascular disease risk, rather than osteoporotic fractures.[16]

Another randomised placebo-controlled trial of 276 postmenopausal women (aged 55 to 65 years) found that an additional 300 g of fruit and vegetables per day (18.5 mEq alkali) did not influence bone turnover or prevent BMD loss over a two-year period.[17] In older populations, a 16-week study showed that five or more portions of fruit and vegetables per day did not alter markers of bone health in healthy, free-living older adults (aged 65 to 85 years),[18] indicating that higher intakes may be needed or that benefits may be less likely at this stage in life.

Overall, these findings indicate that the health benefits of fruit and vegetables may be confined to people who eat little or no fruit and vegetables.[17] Further work is now needed to investigate the roles of individual fruits and vegetables and 'how much' of each of these is needed for optimal bone health.[17] It is also possible that higher intakes, as seen in the Scarborough Fair Diet, i.e., nine or more fruit and vegetable servings daily may be warranted to see improvements in markers of bone turnover.[15] Fruit and vegetable intakes appear to have a life-long rather than a short-term effect on bone health, becoming particularly important at life stages where bone loss is accelerated, e.g., in middle-aged women.[19]

Dairy foods

Protein, calcium, inorganic phosphate and vitamin D all have a role to play in bone and skeletal muscle integrity, with dairy and fortified dairy foods being important sources of these nutrients.[20] Evidence from RCTs studying the effects of dairy consumption in relation to bone health were reviewed.

Metabolic research randomised 16 women (aged 20 to 30 years) to different wholefoods providing about the same amount of phosphorous. Results showed that cheese consumption significantly reduced serum parathyroid

Table 1. Randomised controlled trials (RCTs) evaluating the effects of wholefoods on bone health

Paper	Participants	Study details	Findings
Fruit and vegetables			
Gunn et al (2015)[15]	n = 50 Postmenopausal F eating ⩾ 9 servings of different vegetables/herbs/fruit	3 months. Group A ate a range of vegetables/herbs/fruit. Group B ate specific vegetables/herbs/fruit with bone resorption-inhibiting properties (Scarborough Fair Diet). Group C ate their usual diet.	Group B demonstrated positive changes in bone turnover markers (lowered CTX, P1NP and urinary calcium).
Neville et al (2014)[18]	n = 82 (65 to 85 years)	16 weeks. Those eating less ⩽ 2 portions of FV per day were randomised to continue normal diet or eat ⩾ 5 portions of FV per day.	No significant differences were seen in bone markers between the 2 and 5 portions/day groups.
McTiernan et al (2009)[16]	n = 48 835 postmenopausal F (50 to 79 years)	8.1 years. Assigned to: (1) Dietary Modification intervention; (2) ⩾ 5 servings of vegetables and fruit; (3) ⩾ 6 servings of grains; or (4) no dietary changes.	A low-fat and high fruit, vegetable and grain diet reduced the risk of multiple falls and slightly lowered hip BMD.
McDonald et al (2008)[17]	n = 276 postmenopausal F (55 to 65 years)	24 months. Assigned to: (1) high-dose potassium citrate; (2) low-dose potassium citrate; (3) 300 g extra FV/day; or (4) placebo.	Two-year potassium citrate supplementation did not reduce bone turnover or increase BMD.
Dairy foods			
Josse et al (2012)[22]	n = 90 premenopausal overweight/obese F	16 weeks. Assigned to: (1) HPHD; (2) APMD; or (3) APLD.	Hypo-energetic diets higher in dairy foods, protein and dietary calcium, with daily exercise. Improved bone health biomarkers, e.g., lowered PTH and increased 25(OH)D.
Merrill and Aldana (2009)[25]	M and F healthy adults	6 months. Plant-based dietary intervention (dairy discouraged).	At six months, urinary type I NTX levels significantly increased in the plant-based diet group compared with the control, indicating bone resorption. Significant decrease in dairy servings/day.
Karp et al (2007)[21]	n = 16 healthy F (20 to 30 years)	24 h. Randomised to obtain phosphorous from meat, cheese, wholegrains or a phosphate supplement.	Cheese led to reduced PTH ($p = 0.0001$) and bone resorption ($p = 0.008$).
Woo et al (2007)[24]	n = 441 F living in Hong Kong, Beijing and China (20 to 35 years)	1 year. Allocated to drink two sachets of milk powder (1000 mg calcium, 80 µg vitamin K(1)) or nothing extra.	No significant differences observed between groups.
Bowen et al (2004)[23]	n = 50 overweight adults	16 weeks. Randomly assigned to iso-energetic diets high in either dairy protein (2400 mg Ca/day) or mixed protein sources (500 mg Ca/day).	The DP diet had a modest advantage over the MP diet by minimising turnover.
Eggs, fish and meat			
Cao et al (2011)[30]	n = 16 postmenopausal F	15 weeks. Ate either a LPLP diet or HPHP diet for 7 weeks each separated by a 1-week break.	Compared with the LPLP diet, the HPHP diet significantly increased serum IGF-I concentrations and significantly reduced serum intact PT concentrations.
Roughead et al (2005)[31]	n = 13 postmenopausal F	14 weeks. Ate 25 g high-isoflavone soy protein (SOY) or an equivalent amount of meat protein (control diet) for 7 weeks each.	Substitution of 25 g high isoflavone soy protein for meat, in the presence of typical calcium intakes, did not improve or impair calcium retention.
Legumes, beans and pulses			
Zhao et al (2016)[33]	n = 90 middle-aged and senile osteoporosis patients	6 months.	Frequencies of bean consumption were significantly higher in the intervention *vs* control group ($p < 0.05$). BMDs of lumbar spine and femoral neck were also significantly higher ($p < 0.05$).
Dried fruit			
Hooshmand et al (2016)[36]	n = 48 osteopenic F (65 to 79 years)	6 months. Assigned to: (1) 50 g of prunes; (2) 100 g of prunes; or (3) control.	Both doses of prunes prevented loss of total body BMD compared with the control ($p < 0.05$).
Hooshmand et al (2014)[37]	n = 160 postmenopausal F	1 year. Randomly assigned to receive 100 g prunes/day or 75 g dried apple/day. All participants received 500 mg Ca plus 400 IU (10 µg) vitamin D daily.	Prunes significantly increase the BMD of the ulna and spine in comparison with the control group.
Hooshmand et al (2011)[38]	n = 160 postmenopausal F	1 year. Randomly assigned to receive 100 g prunes/day or 75 g dried apple/day. All participants received 500 mg Ca plus 400 IU (10 µg) vitamin D daily.	Prunes significantly increased BMD of ulna and spine in comparison with dried apple.
Arjmandi et al (2002)[39]	n = 58 postmenopausal F not on HRT	3 months. Assigned to eat 100 g prunes or 75 g dried apples. Both regimens provided similar amounts of calories, fat, carbohydrate and fibre.	Only prunes significantly increased serum levels IGF-I and BSAP, both associated with greater rates of bone formation.
Beverages			
Mahabir et al (2014)[40]	n = 51 postmenopausal F	8 weeks. Studied effects of: no alcohol, low (1 drink or 15 g/d) and moderate (2 drinks or 30 g/d) alcohol consumption on markers of bone health.	Compared with no alcohol, 1 or 2 drinks/day for 8 weeks had no significant impact on any of the bone markers.
Kristensen et al (2005)[41]	n = 11 healthy M (22 to 29 years)	10 days. Given a low-calcium diet with: (1) 2.5 L of Coca Cola per day; or (2) 2.5 L of semi-skimmed milk.	An increase in serum phosphate ($p < 0.001$), 1,25(OH)2D ($p < 0.001$), PTH ($p = 0.046$) and osteocalcin ($p < 0.001$) was observed in the cola compared with the milk group.
Sodium			
Ilich et al (2010)[43]	n = 136 healthy, postmenopausal, Caucasian F	3 years. After baseline, half reduced sodium intake to 1500 mg/day. The other half remained on around 3000 mg/day.	Results showed that participants with higher sodium intake had higher BMD in the forearm and spine at baseline and all subsequent time-points ($p < 0.01$).
Teucher et al (2008)[44]	n = 11 postmenopausal F	20 weeks. Took part in four 5-week periods of interventions (518 *vs* 1284 mg calcium and 3.9 *vs* 11.2 g salt).	Moderately high salt intake (11.2 g/day) elicited a significant increase in urinary calcium excretion ($p = 0.0008$) and significantly affected bone calcium balance with the high calcium diet ($p = 0.024$).

25(OH)D, Calcifediol; 1, 25(OH)2D, Calcitriol; APLD, adequate protein low dairy; APMD, adequate protein medium dairy; BMD, bone mineral density; BSAP, bone-specific alkaline phosphatase; CTX, cross-linked C-telopeptides; DP, dairy protein; F, female; FV, fruit and vegetables; HPHD, high protein high dairy; HPHP; high protein and high PRAL; HRT, hormone replacement therapy; IGF-1, insulin-like growth factor-I ; LPLP, low protein and low PRAL; M, male; MP, mixed protein; NTX, urinary cross-linked N-telopeptides; OPG, osteoprotegerin; P1NP; Procollagen type 1 N propeptide; PRAL, potential renal acid load; PTH, parathyroid hormone; RANKL, receptor activator of NF-kappaB ligand

Table 2. Meta-analysis papers focusing on supplement use in relation to bone health

Paper	Supplement of focus	Findings
Darling et al (2009)[47]	Protein	Protein supplementation had a small, positive effect on lumbar spine BMD.
Avenell et al (2014)[45]	Vitamin D	Vitamin D alone is unlikely to prevent fractures in the doses and formulations tested so far in older people. Supplements of vitamin D and calcium may be required to prevent hip or any type of fracture.
Reid et al (2014)[65]	Vitamin D	A small benefit at the femoral neck was seen but no effects at other sites.
Chung et al (2011)[62]	Vitamin D	Combined vitamin D and calcium supplementation can reduce fracture risk, but effects are smaller among community-dwelling older adults than for institutionalised elderly participants.
Bischoff-Ferrari et al (2005)[46]	Vitamin D	Oral vitamin D supplementation between 700 to 800 IU/day may reduce the risk of hip and non-vertebral fractures in ambulatory/institutionalised elderly persons.
Tai et al (2015)[48]	Calcium	Increasing calcium intake from dietary sources or supplements produces small non-progressive increases in BMD.
Fang et al (2012)[49]	Vitamin K	Vitamin K supplementation was shown to increase BMD at the lumbar spine but not the femoral neck.
Fenton et al (2009)[29]	Phosphate	No evidence was found linking phosphate intake to demineralisation of bone or to calcium excretion in the urine.

BMD, bone mineral density

hormone and levels of bone resorption when compared with other foods, or a phosphate supplement.[21]

Two studies looked at inter-relationships between dairy consumption and bone health during periods of weight loss. In a RCT of 90 overweight and obese women, a daily diet higher in protein (30% energy), dairy foods (15% energy from protein foods) and dietary calcium (1600 mg) significantly improved markers of bone health, osteocalcin and P1NP, when coupled with exercise over 16 weeks.[22] Equally, other work has found that dairy rather than mixed protein prevented bone resorption in overweight adults also taking part in a weight reduction programme.[23]

In China, dairy intakes are habitually low. One study providing sachets of milk powder for two years found that this did not alter BMD or bone biomarkers when compared with controls, possibly due to lack of compliance.[24] Interestingly, findings from a plant-based dietary intervention found that dairy, calcium and vitamin D intakes were significantly reduced after six weeks. Furthermore, urinary type I collagen N-telopeptide levels were significantly higher, implying increased levels of bone resorption.[25]

Taken together, these findings indicate that dairy foods could promote bone health. That said, it should be considered that dairy products vary widely in their nutritional content, with milk and yoghurt appearing to be most beneficial.[26] Equally, the nutrient quality and bio-availability of non-dairy milks such as almond, oat, rice and soy varies, so these should not be regarded as a substitute until this is better established.[27] On a final note, it seems that young women aged < 30 years are most likely to benefit from eating dairy foods, or those with low habitual intakes, although RCTs on men and ethnic minority groups are needed.[26]

Eggs, fish and meat

Dietary protein from mixed sources provides key nutrients for bone health, thereby playing a role in osteoporosis prevention.[28] For meat, dietary advice implying that this is detrimental to bone health (due to its acidic phosphate content) is regarded as unfounded and not fully supported by scientific evidence.[29] This theory has been tested by Cao et al.[30] In a randomised crossover study conducted on 16 postmenopausal women, a high protein and high-potential renal acid load diet did not affect markers of bone metabolism, indicating no adverse effects on bone health.

Other work has looked at whether controlled substitution of soy for meat protein influences bone biomarkers. After seven weeks of eating 25 g soy or meat protein daily no differences were observed in terms of levels of calcium retention or indicators of bone health.[31] While studies looking specifically at the effects of eggs and fish are lacking, links between meat and poor bone health are unconvincing. It is thought that more attention should be given to increasing fruit and vegetable intakes, rather than reducing protein intake.[32]

Legumes, beans and pulses

Only one study has investigated the effect of beans and this was among other dietary changes.[33] Middle-aged and senile patients with osteoporosis ($n = 90$) were randomised to a dietary education/intervention or control group. After the intervention, among other dietary improvements the frequency in which beans were eaten increased. Furthermore, the BMD of the lumbar spine and femoral neck were significantly improved.[33] While diet therapy may improve bone health in osteoporosis patients, more research is needed looking at the focused effects of this food group.

Dried fruit

In addition to key nutrients, fruits provide an array of bioactive compounds and anti-oxidants that may have notable roles in bone health.[34] Emerging evidence suggests that fruits such as dried plums, known commonly as prunes (*Prunus domestica* and *Prunus salicina*), contain

Table 3. European Commission bone health claims, authorised following scientific review by the European Food Safety Authority[50]

Nutrient	Authorised health claim
Protein	Protein is needed for normal growth and development of bone in children
Protein	Protein contributes to the maintenance of normal bones
Calcium	Calcium is needed for the maintenance of normal bones
Calcium	Calcium is needed for normal growth and development of bone in children
Calcium	Calcium helps to reduce the loss of bone mineral in postmenopausal women. Low BMD is a risk factor for osteoporotic bone fractures
Calcium and vitamin D	Calcium and vitamin D are needed for normal growth and development of bone in children
Calcium and vitamin D	Calcium and vitamin D help to reduce the loss of bone mineral in postmenopausal women. Low BMD is a risk factor for osteoporotic bone fractures
Magnesium	Magnesium contributes to the maintenance of normal bones
Manganese	Manganese contributes to the maintenance of normal bones
Phosphorous	Phosphorus is needed for the normal growth and development of bone in children
Phosphorous	Phosphorus contributes to the maintenance of normal bones
Vitamin D	Vitamin D is needed for normal growth and development of bone in children
Vitamin D	Vitamin D contributes to normal absorption/utilisation of calcium and phosphorus
Vitamin D	Vitamin D contributes to normal blood calcium levels
Vitamin D	Vitamin D contributes to the maintenance of normal bones
Vitamin D	Vitamin D helps to reduce the risk of falling associated with postural instability and muscle weakness. Falling is a risk factor for bone fractures among men and women aged 60 years and older
Vitamin K	Vitamin K contributes to the maintenance of normal bones
Zinc	Zinc contributes to the maintenance of normal bones

BMD, bone mineral density

significant amounts of vitamin K1, boron, copper and potassium, sorbitol, quinic acid and chlorogenic acids, which may have positive effects on bone health.[35-38]

Four RCTs were reviewed,[36-39] as shown in Table 1. Their overall effects were in a positive direction. A RCT of 58 postmenopausal women found that prunes (100 g/day) significantly increased serum levels of insulin-like growth factor-I and bone-specific alkaline phosphatase activity, associated with higher rates of bone formation compared with 75 g dried apples over three months.[39]

A large study of 160 postmenopausal women found that prunes (100 g/day) significantly improved BMD of the ulna and spine compared with dried apple control group, suppressing bone turnover.[38] Further analysis of this work showed that the positive effects of prunes on bone were conceivably linked to the suppression of NF-kappaB ligand (RANKL), while promoting osteoprotegerin and inhibiting sclerostin.[37]

Among 48 osteopenic women (aged 65 to 79 years old), eating 50 g of prunes over a six-month period was as effective as eating 100 g, preventing total BMD loss. TRAP-5b, a marker of bone resorption, also reduced at three months and was sustained at six months in both groups.[36]

These findings indicate that dried fruits, especially prunes, may have an important role to play in preserving bone health, particularly that of postmenopausal women. It also appears that only 50 g per day is sufficient to prevent BMD loss.[36]

Beverages

Focusing on published RCTs, two key studies were identified.[40,41] With regards to alcohol consumption, a trial of 51 postmenopausal women were randomised to no, low or moderate alcohol intake over eight weeks. Compared with no alcohol, one or two drinks/day had no significant impacts on any bone markers.[40]

A small-scale study on 11 healthy men (aged 22 to 29 years) found that high intake of cola (2.5 l per day) increased bone turnover when coupled with a low-calcium diet over a ten-day period. Subsequently, authors concluded that cola and other soft drinks should not replace milk in the diet, as this appears to contribute to low calcium intake, having adverse effects on bone health.[41] Nevertheless, more RCTs are needed to study the impact of different beverages on bone health.

Sodium

Dietary sodium is thought to influence urinary calcium excretion, with high intakes linked to increased excretion and elevated bone resorption markers associated with bone loss although the presence of other nutrients such as calcium or potassium may also affect this.[42] Two RCTs explored the effects of sodium on bone health.[43,44]

In one study of postmenopausal women, higher sodium intakes (3000 mg/day; equivalent to about 7.6 g salt) were associated with higher BMD in the forearm and spine.[43] However, another crossover trial of postmenopausal women following a low and high salt diet (3.9 g/day *versus* 11.2 g/day) found that high salt intakes elicited significant increases in urinary calcium excretion, adversely impacting on bone calcium levels.[44] Differences in sodium/salt intakes may have contributed to differences in findings. Ongoing research is needed to clarify interrelationships between the two.

Supplements

Most meta-analytical work has focused on the use of vitamin D supplements in relation to bone health (Table 2). The general consensus appears to be that vitamin D alone is unlikely to prevent fractures in the doses and formulations tested so far in older people. It appears that supplements containing vitamin D and calcium may be required to prevent hip or any type of fracture, though continued research is needed.[45] Other meta-analytical work shows that the efficacy of vitamin D supplements appears to depend on the population under investigation and dose used. For example, higher doses (17.5/20 µg; 700/800 IU daily) may be required to reduce hip and non-vertebral fracture risk among ambulatory elderly individuals.[46]

There appears to be some emerging benefits for protein,[47] calcium[48] and vitamin K[49] in relation to small BMD improvements, though better quality RCTs are needed along with research to see if these reduce fracture risks in the longer term. Evidence looking at phosphate supplementation and markers of bone homeostasis was inconsistent,[29] though lack of findings indicates that advice to avoid acidic foods with a high phosphate content need to be re-evaluated.

Key nutrients for bone health

As shown in Table 3, the European Commission have authorised a number of nutrient function health claims in relation to bone health, following scientific review by the European Food Safety Authority (EFSA). These focus predominantly on protein, calcium and vitamin D, with claims also for magnesium, manganese, phosphorous, vitamin K and zinc.[50]

European Union (EU) authorised claims require submission of high quality, human RCT research consensus to support a claim and this is reflected in the claims permitted. However, other nutrients, including vitamins B, C and K, selenium, copper, iron, boron and silicon, may also have roles to play in relation to bone health.[51,52] For example, selenium deficiency can affect bone and cartilage and copper deficiency may lead to reductions in lysyl oxidase, an enzyme that supports collagen fibril crosslinking, while mechanisms related to iron deficiency are yet to be identified.[51] Emerging evidence from the Aberdeen Prospective Osteoporosis Study has found that silicon interacts with oestrogen and could be important in maintaining the bone health of middle-aged women.[53]

The trace mineral boron is also needed for bone growth and maintenance, with advice that 3 mg/day via supplementation could benefit individuals whose diets are lacking in fruit and vegetables, or who are at risk of osteopaenia or osteoporosis.[54] However, as noted earlier in this review, it may be more effective to encourage individuals to consume sufficient fruit and vegetables, so they can benefit from the wider array of nutrients and bioactive compounds supplied.[15,55]

A review of the EU Register of health claims indicates that, to date, boron and silicon are among a larger number of nutrients considered by the EFSA in relation to bone health. The EFSA has concluded that there is currently insufficient research to demonstrate a cause and effect relationship for these nutrients and bone health, so more research is needed.

Discussion

A balanced diet containing all the food groups in the correct proportions is a good insurance against bone health problems, as well as other chronic diseases, such as cardiovascular disease, obesity and cancers. This not only provides protein, vitamins, minerals and trace elements needed for healthy bones, but also phytonutrients and other bioactive components which have been increasingly linked to improved skeletal integrity.[10,11] While dairy foods are commonly linked to bone health, fruit and vegetables, including dried fruits, also appear to be important modifiable protective factors.[56,57]

Findings from the latest United Kingdom National Diet and Nutritional Survey (between 2015 and 2016) have highlighted that only 8% of children aged 11 to 18 years and 27% of adults aged 19 to 65 years met the Five-A-Day recommendation for fruit and vegetable consumption.[58] This is concerning given that fruit and vegetables are potassium-rich and bicarbonate-rich foods, which have been positively linked to indices of bone health.[12] It has also been identified that a substantial proportion of adults aged $\geqslant$ 19 years (especially women) have intakes of iron, magnesium, potassium and selenium below the Lower Reference Intake.[58] Dietary shortfalls in trace elements, in particular, are thought to have a mechanistic impact on skeletal tissues, possibly impacting on skeletal health.[51]

Dried fruits are a food group that has a general tendency to be overlooked. For prunes, these provide significant amounts of vitamin K, boron, manganese, magnesium, copper and potassium[35] along with high amounts of anthocyanins, with anti-oxidant properties.[57] As highlighted in the present review, findings from four studies consistently reported benefits in relation to markers of bone health.[36-39] Other traditional dried fruits (apricots, dates and raisins) are high in potassium and a source of manganese, but only prunes are also rich in vitamin K.[35] Traditional dried fruits are a convenient snack food that could be encouraged as a healthier alternative to many popular, high fat/sugar/salt snacks, with the added benefit of contributing positively to bone health.

In the case of vitamin D, deficiency is widespread, with food fortification and supplementation programmes

regarded as ways to help prevent osteomalacia and rickets globally.[59] While food sources such as oily fish, eggs and meat can provide vitamin D, there is a general tendency for these to be under-consumed.[60] Skin synthesis via sunlight is also an important source of vitamin D, particularly during the summer months (April to September in the United Kingdom). Outside these months, food and supplement sources become increasingly important and dietary recommendations assume minimal sun exposure all year.[61] Further meta-analytical evidence also indicates that vitamin D supplementation could benefit the bone health of older, institutionalised populations.[45,46,62] That said, in the general population, supplements should not replace a good diet containing a wealth of important functional components[10] that work beyond bone health. Aside from drug therapies, it is also thought that improving nutrient intake across the whole lifetime may help to prevent disability, protect health and improve economic productivity.[4]

On a final note, while a healthy and balanced diet is important throughout the lifespan, skeletal integrity becomes more vulnerable at certain life stages. For example, when bone loss is accelerated in middle-aged women, increasing fruit and vegetable and silicon intakes were found to affect this positively.[15,53] Our review indicates that a 'wholefoods' approach is required to prevent osteoporosis. While it is recognised that other factors including genetics, low body weight, smoking, race and medication use can all affect osteoporosis risk,[63] eating a healthy, varied and balanced diet throughout the lifespan and especially during sensitive windows of bone turnover may help to offset osteoporosis risk.

Nutrition may also have a role in the prevention of secondary fractures.[4,64] For example, orthopaedic surgeons could play a leading role in helping to avoid subsequent fractures by means of dietary and lifestyle measures, given that half of patients with hip fractures have had a previous fracture.[64] As scientific evidence begins to gather for nutrients other than calcium and vitamin D, it is likely that the EU register of authorised claims around bone health will increase.

Osteoporosis is a prevalent skeletal disease characterised by reduced bone mass and deterioration of bone tissue. Ensuring that foods with bone-protecting properties are eaten throughout the lifecycle may help to reduce susceptibility to fractures. Alongside sufficient fruit and vegetable and dairy intakes this can also include encouraging dried fruit such as prune consumption. While most of the focus has been on calcium and vitamin D intakes and co-administration of these to reduce fracture risk,[65] it should be considered that a spectrum of nutrients and trace elements are needed for bone health, with phytonutrients and bioactive compounds in foods also having a seemingly important role. Hence, a wholefood approach would be a more assured way to preventing osteoporosis.

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ICMJE CONFLICT OF INTEREST STATEMENT

All authors work for or on behalf of Food to Fit Ltd., a nutrition consultancy with independent, registered nutritionists and dietitians who work on a self-employed basis. Food to Fit Ltd. provides nutrition advice for several generic food commodity brands including the California Prune Board to whom we are grateful for funding our time to carry out the background research and writing for this paper. The content of this paper is entirely the work of the authors and the funders had no input into the planning or content, and had not reviewed the paper prior to submission.

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The author or one or more of the authors have received or will receive benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this article.

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