Research Article

Peak Bone Mass and Asthi Sarata: A Narrative Review Integrating Modern Skeletal Physiology with Ayurvedic Concepts of Bone Health

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Abstract:

Introduction: Peak Bone Mass (PBM) is the greatest bone mineral content acquired by an individual at the end of skeletal maturation. Asthi Sarata (quality of bone tissue) in Ayurveda reflects the qualitative aspect of bone tissue and may give a complimentary understanding to existing knowledge regarding bone tissue health. Yet, the connection between the two concepts remains unknown.

Methodology: Narrative literature review was carried out using databases like PubMed and Scopus and also traditional Ayurvedic classics like Charaka Samhita, Sushruta Samhita, and Ashtanga Hridaya. The literature was screened for publications from the year 2010 to 2025 using targeted literature search. Evidence obtained was synthesized using thematic analysis.

Results: Contemporary views on bone physiology include osteoblast-osteoclast coupling, hormonal signaling, mechanotransduction, and achieving PBM as primary factors contributing to skeletal health. In Ayurveda, importance is placed on the involvement of Dosha, Dhatvagni, Prakriti, and Asthi Sarata in preserving bone tissue integrity. Current findings support possible correlations between Asthi Sarata evaluation and bone mineral density, whereas there are some parallels between Vata derangement and catabolic bone metabolism as well as Kapha balance and anabolic bone metabolism.

Conclusion: Integrated treatment based on evidence-based nutrition, physical activity, and pharmacology with Ayurvedic approaches customized for each constitutional type may offer additional means for bone health optimization. Further research involving well-conducted clinical and translational studies is necessary to confirm diagnostic methods and treatments related to bone health in Ayurveda.

Keywords: Peak bone mass; Asthi Sarata; Ayurveda; Osteoporosis; Integrative medicine.

1. Introduction

Peak Bone Mass and Asthi Sarata: From Modern Skeletal Physiology to the Ayurvedic View on the State of Bone Tissue

Peak bone mass (PBM) means the maximal quantity of bone tissue reached at the end of skeletal maturation and is one of the most important parameters characterizing long-term skeletal health.[1] The PBM determines the starting point for age-related bone resorption and serves as the main marker of bone loss and osteoporosis.[2] There are different ages of reaching PBM depending on skeletal site and sex; currently, it is believed that PBM is achieved between 18 and 35 years of age.[1]

The state of bone tissue according to Ayurveda is determined by the term of Asthi Sarata, which stands for the excellence of Asthi Dhatu (bone tissue).[3] People are categorized into three groups according to their bone tissue status: superior (Sarva Sara), moderate (Madhya Sara), and poor (Asara) depending on special clinical criteria.[3] The correlation of Asthi Sarata with modern criteria of bone health has been recently studied. Some preliminary observational studies have indicated correlations between Asthi Sarata testing and BMD, including those taken by dual-energy X-ray absorptiometry (DXA). However, the available evidence remains limited and requires confirmation in larger, well-designed studies..[4,5]

Despite the different philosophies that characterize contemporary bone physiology and Ayurvedic physiology, it is evident that both focus on the need for optimal bone health through life. While the former deals with the regulation of bone turnover based on cellular, hormonal, mechanical, and genetic factors, the latter explains bone health through Dosha balance, Dhatvagni, Prakriti, and Asthi Sarata. Integration of the two theories might give a better understanding of skeletal physiology and pave way for personalized bone health interventions.

To our knowledge, no previous review has comprehensively integrated modern concepts of peak bone mass with the Ayurvedic concept of Asthi Sarata while discussing molecular mechanisms, chronobiology,

constitutional assessment, and personalized skeletal health. This review aims to bridge these knowledge domains and identify future research priorities.

2. Methods

A narrative literature review was performed to investigate the relationship between peak bone mass, current skeletal physiology, and the Ayurvedic concept of Asthi Sarata. Targeted searches were conducted in PubMed, Scopus, Web of Science, and Google Scholar for relevant literature from 2010 to 2025. Search strings included combinations of the keywords "peak bone mass," "bone mineral density," "bone remodeling," "osteoblast," "osteoclast," "Asthi Dhatu," "Asthi Sarata," "Prakriti," "Dosha," "Ayurveda," and "bone health." Peer-reviewed papers such as systematic reviews, meta-analyses, randomized controlled trials, observational studies, experiments, and any other relevant literature were included. Ancient Ayurvedic texts such as Charaka Samhita, Sushruta Samhita, and Ashtanga Hridaya were also consulted for understanding Asthi Dhatu and Asthi Sarata. Additional literature was found via manual searching of references. Established knowledge, preliminary associations, and theoretical relationships between current skeletal physiology and Ayurvedic concepts were narratively synthesized.

Since it is a narrative review, there was no need for a systematic review protocol, a meta-analysis, or even a risk-of-bias assessment.

Results

3.1 Physiological factors of modern peak bone mass

Osteoblast-osteoclast coupling in the development of bones

The development of peak bone mass requires coordinated osteoblast-osteoclast interaction.[6] In childhood and adolescence, osteoblast-osteoclast coupling is shifted toward osteoblastic activity, leading to an increase in bone mass.[7] There are various types of signaling pathways regulating osteoblast-osteoclast interaction, which are represented by direct cell-cell interaction through ephrin/Eph systems and secreted factors, namely M-CSF, RANKL/OPG, and Wnt proteins.[6]

Osteoclasts secrete signaling molecules affecting bone formation, thus changing the previous view on osteoclasts as merely resorptive cells.[8] The molecules secreted by osteoclasts are called "clastokines" and include sphingosine-1-phosphate and CTHRC1, which are responsible for the recruitment of osteoblasts.[8] In the course of PBM formation, osteoblasts differentiation from mesenchymal stem cells occurs under the action of TGF-β, BMPs, and Wnt/β-catenin signaling pathways.[9] Canonical Wnt signaling pathway.

The hormonal factors involved in the regulation of the skeletal changes during puberty that lead to maximum bone mass are sex steroid hormones, such as estradiol and testosterone.[11] The increase in both sex steroids and bone formation and bone resorption markers is observed during peri-pubertal growth and is maximal mid-puberty.[11] IGF-1, an osteoblast proliferation agent, is progressively increased during puberty.[11] The effect of parathyroid hormone (PTH) on bone formation is rather controversial, as intermittent PTH treatment promotes osteoblast activity, while hyperparathyroidism leads to bone loss.[12]

Distinctive patterns are seen during puberty in the levels of bone turnover markers, where there is a maximum mid-puberty and reduction towards adult levels late in puberty.[11]

3.2 Genetic and environmental determinants of peak bone mass

Peak bone mass is highly heritable, with genetic determinants of 60-80% of bone mineral density variability found in studies on twins and families.[13] Genome wide association studies have established many loci related to BMD, but the size of the effects is small and indicates polygenic inheritance and gene environment interaction.[13] Loci involved in bone diseases with Mendelian inheritance, established in linkage studies, are crucial regulators of bone mass and affect BMD in the general population.[2]

The QTL mapping in animal models has shown many loci affecting bone mass phenotypes.[2] Population specific loci have been discovered; for instance, the locus 4q22.1 is a risk factor of osteoporosis in Han Chinese population with the SNP rs6532023 associated with bone mineral density.[14] In addition to the genes mentioned above, the FUBP3, p75NTR, and Tsc1 genes have been found to regulate postnatal bone mass in independent studies.[15–17]

Nutritional and lifestyle factors regulating peak bone mass

The lifestyle factors contribute 20-40% to adult peak bone mass that can be modified to increase bone mass.[1] The basic nutrition factors include calcium and vitamin D; studies have shown the benefits of calcium and vitamin D to the PBM especially during late childhood and peri-puberty period.[1] The daily requirement of

calcium intake (1000-1300 mg) is vital for bone mineralization, while vitamin D (600-1000 IU) controls the intestinal calcium absorption.[18],[19]

The physical activity during the growing period influences the skeleton development. The accumulated physical activity is associated with the increased tibial failure load and femoral neck areal BMD.[20] Physical activity during the growing period is strongly related to the trabecular but not to the cortical bone density, depending on the gender.[20] High-impact exercise like jumping contributes better trabecular bone gains than low-impact exercises; exercise programs are successful in PBM.[21]Skeletal development is affected by body composition, with childhood and adult BMI influencing bone geometry changes, where BMI affects long bone dimensions.[22] The state of motor competence affects bone mineral density, such that low motor competence leads to decreased BMD in load-bearing areas.[23] Engaging in multidirectional sports in childhood develops a stronger skeleton.

3.3 Nutritional factors promoting peak bone mass attainment

Mineral-vitamin interactions in bone developmentInteractions between minerals and vitamins are important for proper bone development. Calcium and phosphorus support the mineral matrix, whereas vitamin D, vitamin K, vitamin A, magnesium, and zinc are needed for osteoblast differentiation and mineralization.[19] Vitamin K2 acts through the function of γ-carboxylation of osteocalcin, thus improving bone quality regardless of bone mineral density.[25]

Vitamin D status of a mother during pregnancy affects the bone development of her offspring through complex interactions.[26] Postnatal supplementation of mothers with vitamin D safely increases the vitamin D status of both mother and infant, but not necessarily the growth of the infant.[27] Vitamin D deficiency in school-age children is linked to metabolic disturbances and delayed bone age.[28] Calcium and vitamin D deficiency in different populations lead to poor bone quality, and fortification and supplementation can be used as prevention.[29]

Protein is crucial for the optimal acquisition of bone mass. Essential amino acids act as a substrate for bone collagen matrix formation and help osteoblasts to perform their functions.[19] An adequate diet that contains protein (1.2 – 1.5 g per kg of body mass during puberty) helps create the structural basis for bone formation.[30] Food habits affect skeletal health; the correlation between the plant-based dietary index score and bone mineral density in young adults may vary depending on the general quality of the diet.[31] The DASH diet with a moderate level of sodium intake is positively correlated with bone mineral density.[32]

3.4 Mechanical Loading and Bone Adaptation

3.4.1 Mechanotransduction in Bone Development

Bone is considered mechanosensitive, as it reacts to mechanical forces due to mechanisms of mechanotransduction. According to Wolff's law, the bone structure changes according to mechanical forces, and Piezo1 is the mechanosensor ion channel of osteoblasts.[33] Mechanical loading leads to the regulation of collagen types by means of YAP-dependent gene expression in relation to osteoclast differentiation.[33]

Mechanical loading initiates signaling pathways in osteoblasts required for bone mass gains due to exercises.[34] Mechanical loading performed in accordance with circadian rhythm affects bone adaptability: loading at an active time induces more bone formation on the endocortex compared to resting times with reduced expression of sclerostin and dickkopf-1.[35] Mechanical loading can enhance bone material characteristics, as it was shown by rapid increase of bone material strength index.[36]

3.4.2 Bone remodeling and microarchitectural adaptation in response to exercise

Different types of exercise exert different influences on trabecular bone microarchitecture. While jumps increase trabecular bone volume through thickening of trabeculae, running increases trabecular number.[37] Both running and jumping in growing subjects improve trabecular bone parameters, but this effect is likely to be reduced after cessation of exercise.[38]

Synergy can be observed with combined interventions; PTH treatment along with mechanical loading exerts an additive effect on bone formation in trabecular bone.[39] An antiresorptive intervention in conjunction with exercise exerts additive effects in terms of bone parameters.[40]

3.5 Asthi Sarata and the Ayurvedic Concept of Tissue Excellence

In Ayurvedic physiology, Asthi Dhatu (bone tissue) is considered as one of the Sapta Dhatus (seven foundational body tissues).[3] The primary functions of Asthi Dhatu include structural integrity and mineral storage, whereas the quality of Asthi Dhatu is known as Asthi Sarata which determines the skeletal integrity.[3] In the case of the Vata-Asthi relationship, Asthi Dhatu is described as the physical seat whereas Vata Dosha is

the resident under the Ashraya-Ashrayee Bhava (seat-resident principle).[41] This implies that the dysfunction of Vata Dosha might affect Asthi Dhatu integrity and the deficiency of Asthi Dhatu might cause disturbances in Vata Dosha, resulting in a vicious pathological cycle.[41]

The classical assessment of Asthi Sara Purusha Lakshanas (characteristics of individuals with excellent bone tissue) includes bone prominence, joint integrity, dental health, and hair/nails condition.[3] In addition to this, development of The development of assessment tools such as the Asthi Sara Assessment Inventory (ASAI) could lead to more reliable assessment of Asthi Sarata in studies; but the psychometric and clinical validity of such tools still need to be independently validated. (ASAI) allows us to classify the bone tissue quality with reproducibility.[46] Some preliminary research has been conducted on the connection between the Asthi Sara assessment and bone mineral density measures.[4],[5]

The hair loss (Keshapatana), which is an aspect of Asthi Dhatu Kshaya (bone tissue deficiency) in Ayurveda, has been studied for its utility as a possible clinical marker of bone health. There was a highly significant negative correlation between hair fall gradings and bone mineral density Z-scores ($r = -0.914$, $p < 0.001$) in a pilot study of women, indicating that classic signs in Ayurveda could be easily used as biomarkers of bone health. However, such observations need to be confirmed in a large cohort.

Dosha vitiation and bone pathophysiology: The Vata-Pitta-Kapha relationship

In Ayurveda, age-related degeneration of the skeleton as well as Asthi Dhatu Kshaya is usually described with respect to Vata Dosha and imbalances in tissue metabolism (Dhatvagni). Aggravated Vata Dosha is described as Ruksha, Chala, and Laghu; these qualities can be seen as similar to some aspects of degenerative bone disease. However, these similarities are merely illustrative and do not indicate biological identity. Modern risk factors for degeneration of the skeleton, such as poor vitamin D and calcium status, hormonal imbalance, inactivity, and abnormal bone turnover, cannot be directly related to Vata or Dhatvagni unless scientific evidence confirms this connection.

The concepts of Pitta and Kapha can also be viewed in relation to Ayurveda in order to describe tissue metabolism and stability. While their correlation with modern theories of bone remodelling and matrix production may serve as hypotheses for future studies, no clear links have yet been proven between these Doshas and osteoblasts, osteoclasts, or any molecular signaling processes. Consequently, these links should be viewed as concepts rather than proven processes at present time.

The Ayurvedic constitution (Prakriti), which is based on dominant doshas, might impact the skeletal health pattern. It is believed that Vata dominant people are more susceptible to the degradation and destruction of bones. Pitta-dominant patients might be more susceptible to inflammation, whereas Kapha dominant patients will have more balanced metabolic activity.[42]

The cross-sectional studies linking Prakriti with biochemical markers showed that there might be some impact of the constitution on metabolic parameters.[43] The combination of Prakriti assessment and modern bone density measurement is the way to personalize the risk stratification, but still, prospective validation studies are needed.[44] Irregular menstrual periods and faster bone loss were described in Vata dominant women in observational studies.[45],[46]

3.6 Ayurvedic methods for improvement in Asthi Sarata

3.6.1 Dietetic approach and Asthi-Poshana (bone nourishment)

The Ayurvedic method of dieting focuses on the use of herbs and food that promote bone tissue and balance dosha.[3] For instance, sesame seeds (Til), known for their mineral content, are some of the foods utilized in promoting bones because of their heating (Ushna) and heaviness (Guru).[3]

The prebiotics such as fructooligosaccharides have been found to be effective in promoting bone mass by selectively stimulating bone formation and increasing the synthesis of short-chain fatty acids.[47] The supplementation of Vitamin D metabolites along with glucosamine sulfate in the diet has also been found to influence calcium metabolism in animal models.[48]

In Ayurveda, specific herbs' combinations are used to target bone tissues. One of the herbs is Cissus quadrangularis (CQ), which is found to be effective in the treatment of bone healing because of its osteogenic potential due to the bioactive components present in it.[49] Various cases have been reported on the improvement of bone diseases due to Panchakarma therapy.[50]

3.6.2 Panchakarma and Rasayana treatment of bone tissue rejuvenation

The Panchakarma treatment consisting of Shodhana (purification) and Shamana (symptomatic treatment) treatment methods allows us to create a scheme of treatment of Asthi Dhatu diseases.[3] The classic literature presents phased approaches to therapy of tissue rejuvenation; however, there are no data about the times of

quantitative recovery of bone mineral density in controlled clinical trials. Basti treatment (medicated enema), especially Ksheera Basti (medicated milk enema) is used in the treatment of Vata-Asthi imbalance.[3,50]
There is evidence on the efficacy of traditional Ayurveda medicine for bone treatment. Randomized controlled trials evaluating the effect of additional use of Panchatikta Ghrita along with vitamin D3 and calcium supplements in patients with osteopenia showed an increase in bone mineral density at 6 and 12 months with significant changes in biomarkers including vitamin D3, osteocalcin, and TRAP-5b.[51] These results indicate the possibility of using classical Ayurveda formulations in bone treatment; however, more randomized trials are required.Rasayana is an Ayurvedic therapy that uses the science of rejuvenation to increase longevity and tissue vitality through the enhancement of agni, proper production of rasa dhatu, and nutrition of the subsequent dhatus.[52,53] Rasayana herbs like Amalaki (Emblica officinalis), Guduchi (Tinospora cordifolia), and Ashwagandha (Withania somnifera) exhibit adaptogenic, antioxidant, and immunomodulating activities.[52,53] Ashwagandha possesses antioxidant and anti-inflammatory activities for the promotion of general wellness.[53] The activity of the herbs occurs through several mechanisms, including digestion.

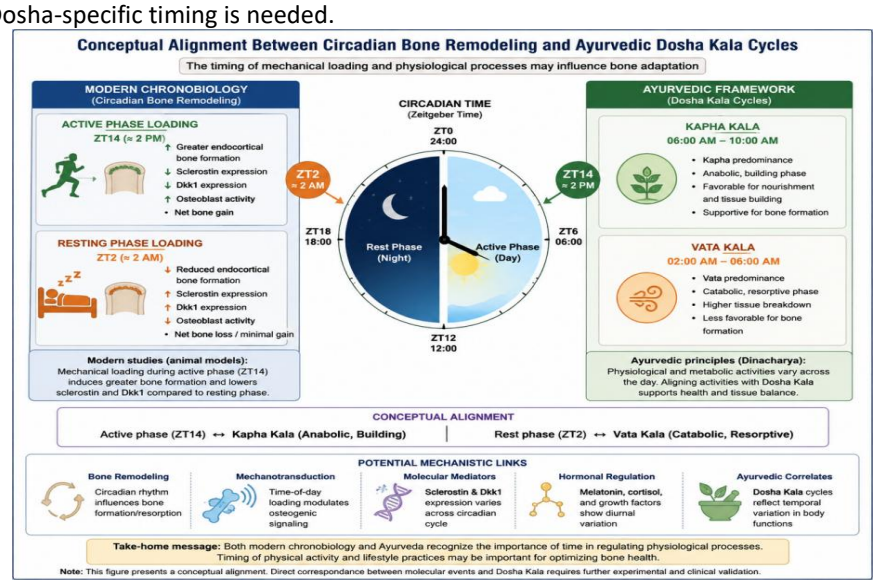
3.6.3 Compounds and phytoconstituents from herbs with osteogenic properties

Studies based on network pharmacology have discovered multi-targeted therapeutic mechanisms of action of osteoporosis-related herbs, and found that natural compounds might work through various mechanisms to improve bone health.[54] Through screening of osteoporosis-related herbs, many natural compounds with desirable pharmacokinetics acting on skeletal-related pathways have been discovered.[54]
Salvia miltiorrhiza (Red Sage Root), which is used in Traditional Chinese Medicine as a bone preserving agent, promotes bone mineral density through osteoblast differentiation and inhibition of osteoclastogenesis.[55] The tanshinone constituents inhibit osteoclastogenesis through MAPK/NF-κB pathways and ethanol extracts enhance osteoblastogenesis through Wnt/β-catenin activation.[55] Further research is needed to validate the clinical use of salvia-based formulations.

7 Integration of Ayurvedic and current views

Connection between the mechanisms of cell action and constitutional theory

Cellular mechanisms involved in osteoblast-osteoclast coupling have some similarities to Dosha theory in Ayurveda. Inhibition of Wnt signaling pathways by sclerostin and dickkopf results in decreased bone formation and could be viewed as a mechanism analogous to the bone-inhibiting effect of aggravated Vata, but there is no clear evidence for it.[10] M-CSF and RANKL, which play an important role in osteoclast differentiation and act as catabolic agents, could be seen as analogs of vitiated Vata.[6] On the other hand, BMP pathway stimulates osteoblastogenesis and is similar to bone-producing effect of balanced Kapha.[7]
Regulation of bone remodeling by circadian rhythms is found to be provisionally harmonized with the Ayurvedic principles of Dosha Kala. There is a diurnal rhythm in the expression of core clock genes and osteocyte-associated genes wherein there is a timed response to mechanical loading of sclerostin (Sost) and dickkopf (Dkk1).[35] Mechanical loading performed at active time (ZT14) leads to more endocortical bone formation than mechanical loading at rest time (ZT2), with decreased expression of sclerostin and dickkopf-1.[35] This observation is in agreement with the Dinacharya (daily regimen) according to natural rhythms; however, the proof for Dosha-specific timing is needed.



Modern models explaining osteoporosis can also be analyzed using the concept of Vata-Asthi imbalance. Estrogen, testosterone deficiencies, nutritional deficiencies, physical inactivity, and metabolism dysfunction that come as the consequence of aging can all be viewed from the perspective of Ayurveda as factors that contribute to Vata imbalance, leading to secondary depletion of the Asthi Dhatu.[3] The bone resorption that is characteristic of osteoporosis and which is dry and irregular corresponds to the characteristics of vitiated Vata (Ruksha, Chala, Laghu); the process of continuous bone depletion also fits into the pattern of Vata disorder.[3]
In terms of Ayurvedic philosophy, the idea can be considered that equilibrium of Doshas may lead to the best possible development and maintenance of tissues. It has yet to be proven whether the state of equilibrium has anything to do with achieving higher peak bone mass, as Vata facilitates osteoblast mobilization, Pitta bone matrix production and Kapha bone stability.[3] Using this model, one could identify doshic imbalances associated with specific bone pathology.

The combination of the assessment of Prakriti with contemporary techniques of bone mineral density could serve as an approach to fracture risk prediction and personalization of preventive measures. Individuals with Vata predominance may require early intervention with grounding and stabilizing approaches; Pitta with cooling and anti-inflammatory approaches; Kapha with stimulating approaches.[3] Several cross-sectional studies investigated relationships between Prakriti and metabolic markers, corroborating the notion of differences in the physiological function of the different body constitutions.[42]
Creating constitution-specific norms for bone markers, utilizing modern diagnostic techniques, and formulating treatment regimens based on constitutional type constitute possible areas for integrative skeletal medicine, however, requiring prospective validation studies.[44]

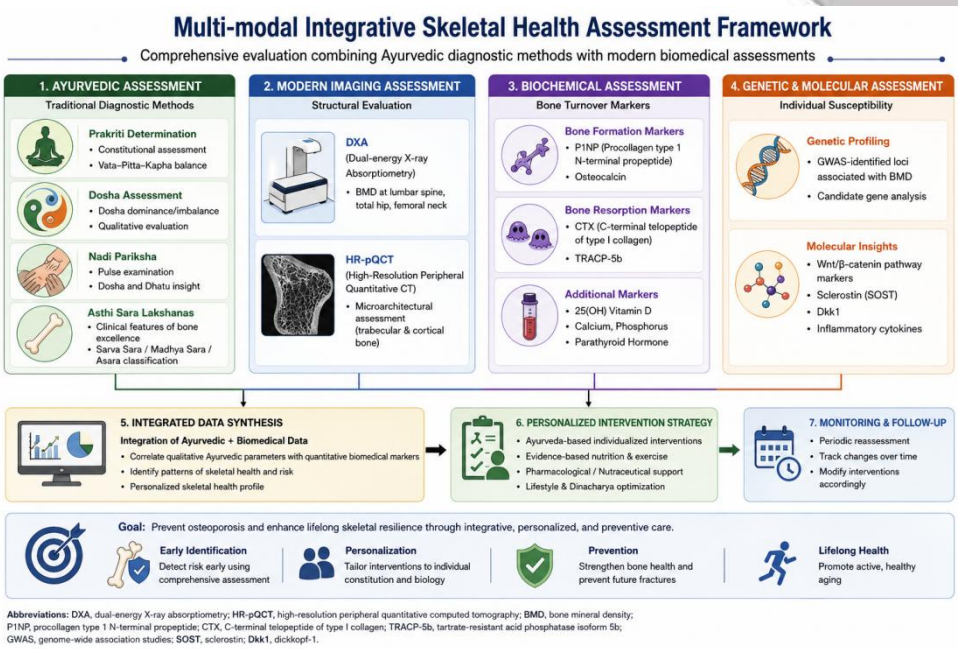
3.8 Systemic considerations and bone health
The gut microbiota influences bone metabolism by several means, including metabolites production (short-chain fatty acids), immune system control, maintaining intestinal permeability, and nutrient absorption.[56] Any changes in the composition of gut microbiota caused by exercise might influence calcium absorption and bone metabolism via the gut-bone axis.[56] Prebiotics, such as fructooligosaccharides, can elevate serum butyrate, which is a short-chain fatty acid that promotes bone formation.[47] Dietary interventions promoting the beneficial composition of the microbiome could be considered.

The Ayurvedic Dinacharya (daily regimen) synchronized with natural cycles can serve as a model for comparison to modern chronobiology. The framework for the Dosha Kala—Kapha (6–10 AM/PM), Pitta (10 AM–2 PM/10 PM–2 AM), and Vata (2–6 AM/PM)—is the classical cycle which describes the physiological activities in time.[3] In modern chronobiology, circadian regulation of bone remodeling gene expressions and hormones as well as metabolic rhythms was identified, but the correlation between those cycles and Dosha Kala cycles was not empirically confirmed.[35]
Principles of waking up before sunrise (Brahma Muhurta) and exercising at certain times during the day can be taken into account with regards to the circadian optimization. Disruption of circadian rhythm patterns is correlated with the risk of metabolic diseases; chronodisruption is discussed as the risk factor for osteoporosis.[57]

The Ayurvedic approach to psychology includes the concept of three Gunas, i.e., Sattva, Rajas, and Tamas, each having specific theoretical importance with regard to the skeletal system. Sattva (balance) facilitates optimum physiological functioning; Rajas (tension) leads to patterns that are unsteady, whereas Tamas (inertia) affects regeneration.[3] It is possible to apply these concepts to the contemporary psychoneuroimmunological research results indicating that psychological stress leads to the HPA dysfunction, increased cortisol levels, and bone resorption.[12] Meditation and yoga focusing on achieving mental equilibrium can be considered evidence-based methods.[58]

3.9 Clinical application
3.9.1 Multi-modal assessment: blending conventional diagnostic techniques with new diagnostic measures
Aspects of Ayurveda like Prakriti, Dosha classification, Nadi Pariksha, and Asthi Sara qualities may be evaluated together with modern tests used to measure bone mass and quality, such as dual-energy X-ray absorptiometry (DXA), quantitative ultrasound, high-resolution peripheral quantitative computed tomography (HR-pQCT), and biomarkers for bone turnover. Such an approach might serve as a basis for studying the correlation between Ayurvedic phenotypic markers and objective criteria of bone mass, quality, and turnover rate. At the moment,

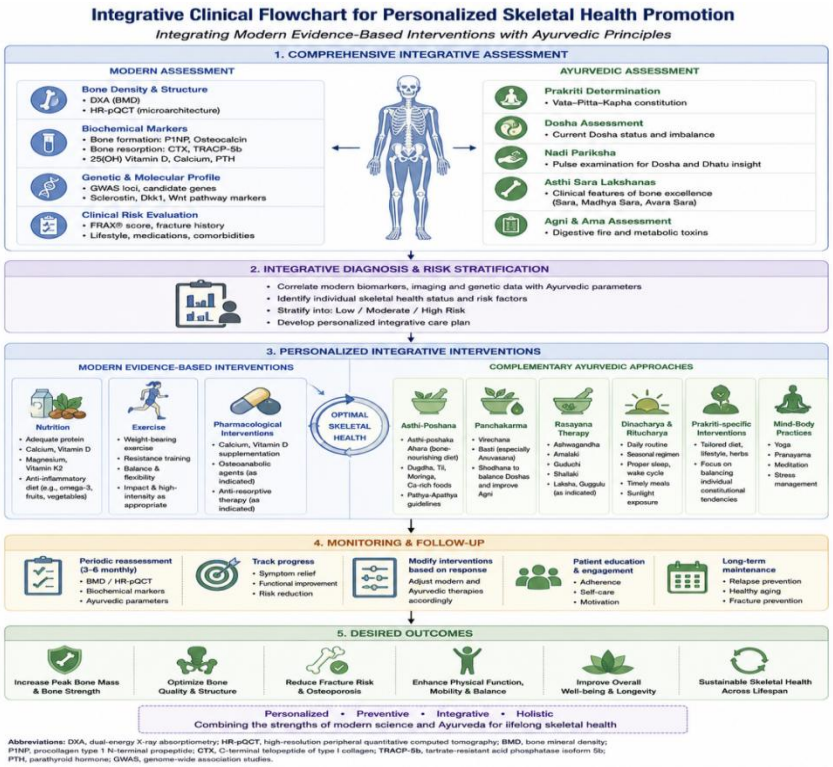
all of these correlations must be regarded as experimental and need validation in carefully conducted clinical trials.



3.9.2 Integrated treatment protocols: integration of Ayurveda and modern treatments

Skeletal health optimization may involve the use of modern evidence-based treatments and also Ayurvedic treatment modalities simultaneously. These evidence-based interventions include proper intake of adequate amounts of calcium (1000-1300 mg daily for adolescents), vitamin D (600-1000 IU daily), and protein[1,19]; regular weight-bearing and resistance exercises[20,21]; and pharmacological interventions (bisphosphonates, PTH analogs) where indicated[12,40].

These Ayurvedic treatment modality options include dietary foods and herbs that promote the well-being of the Asthi Dhatu and balance the Dosha patterns in an individual[3]; Panchakarma treatment options (Basti, Abhyanga, Swedana) for detoxification and rejuvenation[50]; Rasayana therapy focusing on longevity-promoting herbs (Amalaki, Guduchi, Ashwagandha)[52,53]; daily and seasonal routines (Dinacharya).



3.9.3 Monitoring and outcome assessment

Monitoring processes may include assessment of modern biomarkers like bone mineral density progression, bone turnover markers, serum calcium, vitamin D, and parathyroid hormone as well as Ayurvedic clinical outcomes such as changes in Asthi Sara state and Dosha balance.[3] Studies applying both of these measuring methods will show the effectiveness of the therapy and allow optimizing it.

3.10 Future technological approches

The novel strategies like AI, ML, multi-omics, and digital health can aid in standardization of phenotyping in Ayurveda and understanding the link between Prakriti, Asthi Sarata, and the objective bone parameters. However, such strategies are at an experimental stage and need validated tools, appropriate datasets, and clinically significant outcomes.

4. Discussion

Peak bone mass is an important factor determining life-long bone health in modern medicine, and Asthi Sarata describes the Ayurvedic paradigm defining the qualitative aspects of bone tissue. From the available literature, preliminary connections have been drawn between the assessment of Asthi Sarata and the measures of bone health traditionally used. Nonetheless, the hypothesized links between Ayurvedic terms like Dosha, Dhatvagni, and Prakriti and cellular/molecular mechanisms involved in bone remodeling are purely speculative and do not exist in the form of biological equivalents. Thus, the combination of the Ayurvedic assessment and the modern measures of bone health represents a novel research framework rather than a clinically proven one. Further prospective, clinical, and translational studies are needed to establish the connection between Asthi Sarata assessment, bone mineral density and turnover, and personalized bone health.

4.1 Limitations

There are multiple limitations associated with this conceptual review. First of all, there is no empirical evidence of mechanistic equivalence when synthesizing Ayurvedic and contemporary models; there is only conceptual equivalence of ideas. Also, there are no direct studies comparing the effects of Doshas on different parameters of bone remodeling. Secondly, most of the treatment methods used in Ayurveda and claimed to be effective in improving bone density are based on literature and clinical experience rather than randomized controlled trials. Thirdly, the assessment techniques of Prakriti and Asthi Sara need further standardization and validation through bone biomarkers. Finally, there was no use of systematic search methodology and meta-analysis in the review, which prevented quantitatively combining effect sizes.

Heterogeneity of Ayurvedic vocabulary, methods of assessing, subject population, and measurement of outcomes also makes comparisons difficult among existing research studies. In addition, the association between Ayurvedic concepts and modern biological pathways is more of a hypothesis-generating process rather than a well-established relationship.

Future directions

Any future study will have to focus on validation of the Asthi Sarata assessment against any objective skeletal parameter, including bone mineral density through dual-energy X-ray absorptiometry, ultrasound indices and other biochemical biomarkers of bone metabolism. Prospective studies are essential to find out whether there is an association between Asthi Sarata and peak bone mass and its consequences. Future studies that will integrate Prakriti and Asthi Sarata assessments with current phenotyping may bring further insight into whether there are associations between Ayurvedic body constitution and certain phenotypes. Moreover, clinical trials with Ayurvedic therapy for bone health are required. Future directions for research may be found in emerging techniques of genomics, metabolomics, microbiomics, chronobiology and artificial intelligence.

Contributions of the Authors

Umesh Ghate Conceptualization, writing, reviewing, and editing. All authors agree to the manuscript's final published version.

Ethical Statement

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The authors declare that there are no conflicts of interest.

Data Availability Statement
No new data was obtained in this narrative review. Data supporting the findings of this review are provided in the paper and in citations made.

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Modern Concept	Ayurvedic Equivalent	Potential Mechanistic Parallel	Current Evidence Level
Peak Bone Mass (PBM)	Asthi Sarata (bone tissue excellence)	Both describe an optimal skeletal state; PBM primarily reflects bone quantity, whereas Asthi Sarata emphasizes tissue quality.	Preliminary association studies[4]
Osteoblast–osteoclast coupling	Dhatvagni (tissue metabolism)	Balanced metabolic activity maintains tissue homeostasis in both frameworks.	Conceptual parallel; no direct experimental validation
Wnt/β-catenin signaling (anabolic pathway)	Balanced Kapha Dosha	Both are associated with bone formation and structural stability.	Conceptual parallel; no direct experimental validation
Sclerostin/Dkk1-mediated inhibition (catabolic pathway)	Vata Dosha vitiation	Both are associated with reduced bone formation and increased bone resorption.	Conceptual parallel; no direct experimental validation
Circadian bone remodeling (e.g., ZT14 loading in animal models)	Dosha Kala (Vata predominance: 2–6 AM/PM)	Both suggest that the timing of physiological processes may influence bone adaptation; direct correspondence remains unverified.	Preliminary evidence from animal models[35]
Bone turnover markers (P1NP, CTX)	Asthi Sara Lakshanas (clinical features of Asthi Sarata)	Both aim to assess bone status using non-invasive indicators; potential correlations are under investigation.	Exploratory/pilot evidence; further validation required[46,61]
Genetic polymorphisms (GWAS loci)	Prakriti (constitutional phenotype)	Both recognize inherent biological variation that may influence skeletal characteristics.	Genomic associations reported; bone-specific validation remains limited[42]
Gut microbiota–bone axis	Agni (digestive fire) and Dosha-specific dietary principles	Both emphasize the importance of digestive function in supporting bone health.	Emerging evidence (microbiota); traditional Ayurvedic concept[56]
Mechanotransduction (e.g., Piezo1 signaling)	Vyayama (exercise), particularly during Kapha Kala	Both recognize mechanical loading as an important stimulus for maintaining skeletal integrity.	Well established in modern research; traditional recommendation in Ayurveda[33,37]
Rasayana interventions (e.g., Ashwagandha, Amalaki)	Rasayana therapy	Both may promote skeletal health through antioxidant and anti-inflammatory mechanisms.	Primarily preclinical evidence; limited clinical studies[51,54]