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Osteoporosis and Ayurveda: A Comprehensive Review of Pathogenesis, Modern Management, and Traditional Perspectives

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Abstract

Osteoporosis is a systemic skeletal disorder characterized by reduced bone mineral density, microarchitectural deterioration, and increased fracture risk, affecting over 200 million people worldwide. While modern pharmacotherapy, including bisphosphonates, denosumab, teriparatide, and romosozumab, has demonstrated efficacy in fracture prevention, concerns regarding adverse effects, long-term compliance, and accessibility have spurred interest in integrative and traditional approaches. *Ayurveda*, the ancient Indian system of medicine, conceptualizes osteoporosis through the framework of *Asthikshaya* (depletion of bone tissue) and *Asthi Saushirya* (porosity of bones), conditions rooted in *Vata dosha* aggravation, *Agnimandya* (impaired digestive fire), and *Dhatukshaya* (tissue depletion). This review synthesizes contemporary biomedical understanding of osteoporosis pathogenesis, including the RANK/RANKL/OPG pathway, oxidative stress, inflammation, and the gut-bone axis, with classical *Ayurvedic* principles and therapeutic strategies. *Ayurvedic* interventions encompass *Panchakarma* procedures (particularly *Basti* medicated enema), herbal formulations (*Lakshadi Guggulu*, *Asthi Shrinkhala* or *Cissus quadrangularis*), *Rasayana* (rejuvenation) therapy, and *Vata*-pacifying dietary and lifestyle modifications. Emerging clinical evidence supports the osteoprotective potential of specific *Ayurvedic* interventions, though rigorous randomized controlled trials are needed for standardization and integration into evidence-based practice. An integrative model combining pharmacological therapy with *Ayurvedic* principles offers a promising pathway for comprehensive osteoporosis management.

Keywords: Osteoporosis, *Ayurveda*, *Asthikshaya*, *Vata dosha*, *Panchakarma*, bone mineral density, integrative medicine, *Basti*, herbal medicine

1. Introduction

Osteoporosis is a systemic metabolic bone disease defined by low bone mass, deterioration of bone microarchitecture, and consequent increase in bone fragility and fracture susceptibility. The global burden of osteoporosis is substantial and escalating with population aging. Data indicate that more than 200 million people worldwide suffer from osteoporosis, with an overall prevalence of 18.3% among adults over 50 years of age [3]. Among individuals aged 50 years and older, approximately 21.2% of women and 6.3% of men are affected. Projections estimate that by 2025, 500 million people will be living with osteoporosis, with 13.5 million fragility fractures occurring annually worldwide [3]. One in three women and one in five men over the age of 50 will experience osteoporotic fractures in their lifetime. Hip fractures, in particular, are associated with a mortality rate of 20–24% within the first year post-fracture, underscoring the critical public health importance of this condition [1].

The pathogenesis of osteoporosis involves a complex interplay of genetic, hormonal, nutritional, and environmental factors. Central to this process is the imbalance between bone resorption by osteoclasts and bone formation by osteoblasts, mediated by the RANK/RANKL/OPG signaling pathway [1]. Estrogen deficiency, particularly following menopause, reduces osteoprotegerin (OPG) activity, permitting increased RANKL-RANK binding and enhanced osteoclast-mediated bone resorption [12]. Chronic inflammation and oxidative stress further exacerbate this imbalance, promoting osteoclast activity while impairing osteogenesis [13]. Emerging research also implicates the gut microbiota-bone axis in osteoporosis pathogenesis, with gut dysbiosis and microbial metabolites influencing bone remodeling through immune and metabolic pathways [17].

Modern pharmacological management of osteoporosis has evolved considerably. Bisphosphonates remain the first-line therapy for most patients, with strong evidence for fracture risk reduction [4]. Denosumab, a RANK ligand inhibitor, serves as second-line therapy, particularly in patients with bisphosphonate contraindications. Anabolic agents such as teriparatide and romosozumab are reserved for patients at very high fracture risk [4]. Despite these advances, challenges persist, including medication adherence, adverse effects (gastrointestinal intolerance, atypical femoral fractures, osteonecrosis of the jaw), high costs, and limited accessibility in low-resource settings [5].

In this context, traditional medical systems offer alternative and complementary perspectives. *Ayurveda*, one of the world's oldest codified medical systems, has addressed bone disorders for millennia. The World Health Organization recognizes traditional medicine as encompassing knowledge, skills, and practices based on theories, beliefs, and experiences indigenous to different cultures [14]. *Ayurveda* conceptualizes health as homeostasis of *Dosha* (biological humors), *Dhatu* (tissues), and *Mala* (waste products). Among the seven *Dhatus*, *Asthi dhatu* (bone tissue) is endowed with the function of *Sharira dharana* providing structural support and protecting vital organs. The equilibrium of *Dhatus* constitutes health, while disequilibrium whether increase or decrease constitutes disease [6].

Osteoporosis finds its correlates in *Ayurvedic* classics as *Asthikshaya* (decrease in bone tissue) and *Asthi Saushirya* (porous bones). *Asthikshaya* is explained under the heading of *Ashtadasha Kshayas* (eighteen types of depletion) by Acharya Charaka [6]. *Asthi Saushirya*, meaning "with pores" (*Sarandhratvam*), is described in the context of *Majjakshaya* (bone marrow depletion). The pathogenesis of *Asthikshaya* is fundamentally linked to *Vata dosha* aggravation, as *Asthi dhatu* is the seat of *Vata*, and these two entities share an inverse relationship increase of *Vata* leads to decrease of *Asthi* [7].

This review aims to: (1) summarize contemporary biomedical understanding of osteoporosis pathogenesis and management; (2) elucidate classical *Ayurvedic* concepts of bone physiology and pathology relevant to osteoporosis; (3) review the evidence for *Ayurvedic* interventions including *Panchakarma*, herbal formulations, and lifestyle modifications; and (4) explore the potential for integrative approaches combining modern and traditional therapies.

2. Methods

This narrative review synthesizes information from classical *Ayurvedic* texts (*Charaka Samhita*, *Sushruta Samhita*, *Ashtanga Hridaya*) and contemporary biomedical literature [6]. A literature search was conducted using PubMed, Scopus, Google Scholar, and AYUSH-specific repositories for publications from January 2000 to December 2024. Search terms included combinations of: "osteoporosis," "bone mineral density," "fracture," "pathogenesis," "RANKL," "management," "bisphosphonates," "denosumab," "teriparatide," "*Ayurveda*," "*Asthikshaya*," "*Asthi Dhatu*," "*Vata*," "*Panchakarma*," "*Basti*," and specific herbal nomenclature. Peer-reviewed articles, clinical trials, observational studies, systematic reviews, and conceptual reviews addressing osteoporosis pathogenesis, modern management, or *Ayurvedic* interventions were included. Relevant information from cross-references was also incorporated.

3. Results

3.1 Modern Biomedical Understanding of Osteoporosis

3.1.1 Bone Remodeling and the RANK/RANKL/OPG Pathway

Normal bone homeostasis depends on the balanced coupling of bone resorption by osteoclasts and bone formation by osteoblasts. Osteoblasts express receptor activator of nuclear factor-κB ligand (RANKL), which binds to RANK

receptors on osteoclast precursors and mature osteoclasts, stimulating osteoclast differentiation, activation, and survival. Osteoblasts also secrete osteoprotegerin (OPG), a soluble decoy receptor that binds RANKL and competitively inhibits RANK activation. The RANKL/OPG ratio determines the net rate of bone resorption [1].

In the presence of estrogen, OPG activity is upregulated, inhibiting osteoclast-mediated bone resorption. Estrogen deficiency the hallmark of postmenopausal osteoporosis reduces OPG activity, increases RANK activation, and results in osteoclastic bone resorption surpassing osteoblast-mediated bone formation. This imbalance leads to progressive bone loss, microarchitectural deterioration, and increased fracture risk [12].

3.1.2 Oxidative Stress, Inflammation, and the Gut-Bone Axis

Beyond hormonal regulation, the pathophysiology of osteoporosis involves cellular senescence, oxidative stress, and chronic inflammation. Reactive oxygen species promote osteoclastogenesis while suppressing osteoblast differentiation and function. Pro-inflammatory cytokines further amplify bone resorption. Estrogen deficiency also dysregulates microRNA expression, contributing to post-transcriptional control of genes involved in bone metabolism [13].

The gut-bone axis has emerged as a significant regulatory pathway. Gut dysbiosis and altered microbial metabolites particularly short-chain fatty acids influence bone remodeling through immune-mediated mechanisms. Germ-free or T-cell-depleted mice do not lose bone after ovariectomy, underscoring the microbiota-immune axis as a mechanistic core of postmenopausal bone loss. This finding opens new therapeutic avenues targeting the microbiome for osteoporosis prevention and treatment [17,18].

3.1.3 Peak Bone Mass and Age-Related Bone Loss

Peak adult bone mass is reached at approximately 35 years of age for cortical bone and slightly earlier for trabecular bone. Bone mass subsequently declines with aging a universal phenomenon occurring in both sexes and all races. At all ages, women have less bone mass than men, and this difference becomes more pronounced with aging. Two major determinants of bone mineral density in later life are: (1) the extent of peak bone mass attained in early adulthood, and (2) the rate of involutional bone loss thereafter. Both determinants are governed by complex interactions of genetic, environmental, nutritional, hormonal, age-related, and lifestyle factors [5].

3.2 Modern Pharmacological Management

Current pharmacological management follows a stepwise approach based on fracture risk stratification.

First-line therapy: Bisphosphonates (alendronate, risedronate, zoledronic acid) are recommended as initial pharmacologic treatment for postmenopausal women and men with primary osteoporosis. Strong evidence demonstrates reduction in hip fractures, clinical vertebral fractures, and radiographic vertebral fractures compared with placebo. Bisphosphonates are cost-effective, available in generic formulations, and have a long-established safety profile despite rare adverse events (atypical femoral fractures, osteonecrosis of the jaw). Calcium (1,000–1,200 mg/day) and vitamin D (600–800 IU/day) supplementation should accompany pharmacologic therapy [4,5].

Second-line therapy: Denosumab, a monoclonal antibody targeting RANKL, is recommended as second-line treatment for patients with contraindications to or adverse effects from bisphosphonates. It offers convenient biannual subcutaneous administration (60 mg every 6 months) and can be used in patients with impaired renal function [4].

Third-line and anabolic therapy: Teriparatide (recombinant parathyroid hormone) and abaloparatide are recommended for severe osteoporosis or patients with fractures, promoting new bone formation rather than merely preventing resorption. Romosozumab, a sclerostin inhibitor, is another anabolic option. All patients treated with anabolic agents should receive sequential antiresorptive therapy to prevent rapid bone loss. Selective estrogen receptor modulators (SERMs) such as raloxifene are reserved for postmenopausal women when other options are not appropriate [4].

3.3 Ayurvedic Conceptual Framework for Osteoporosis

3.3.1 The *Dosha-Dhatu-Mala* Theory and *Asthi Dhatu*

Ayurveda conceptualizes the human body as a congenial homeostasis of *Dosha*, *Dhatu*, and *Mala*. The function of *Dhatus* is *Dharana* (support) of the *Sharira* (body). Among the seven *Dhatus* (*Rasa*, *Rakta*, *Mamsa*, *Meda*, *Asthi*, *Majja*, *Shukra*), *Asthi dhatu* is specifically responsible for *Sharira dharana* it provides structural form to the body and protects vital organs [6].

Asthi dhatu is primarily composed of the *Prithvi* (earth) and *Vayu* (air) *Mahabhutas* (great elements), imparting stability and porosity respectively. According to the principle of *Ashraya-Ashrayee Bhava* (substrate-substrate relationship), *Asthi dhatu* serves as the seat (*Ashraya*) of *Vata dosha*. This relationship is reciprocal and inverse: *Asthi* and *Vata* are inversely proportional in their increase and decrease aggravation of *Vata* leads to depletion of *Asthi* [6].

3.3.2 *Asthikshaya*: Clinical Features and Pathogenesis

Asthikshaya (depletion of bone tissue) is described as one of the *Ashtadasha Kshayas* (eighteen types of depletion) in the *Charaka Samhita*. Classical descriptions of *Asthikshaya* include clinical features that closely parallel osteoporosis [6]:

- *Asthi Shoola* or *Toda*: bone pain and pricking pain in bones
- *Sandhi Shaithilya*: joint laxity and instability
- *Danta–Nakha–Kesha Vikara*: degenerative changes of teeth, nails, and hair
- *Raukshya*: dryness of skin and tissues
- Early fatigue and generalized weakness
- *Aswapna*: sleep disturbances
- *Satataruka*: continuous pain

Asthi Saushirya (porous bones), meaning "with pores" (*Sarandhratvam*), is described in the context of *Majjakshaya* (bone marrow depletion). Both conditions represent different dimensions of the same degenerative process reduction in bone quantity and increase in bone porosity [6].

The pathogenesis of *Asthikshaya* involves multiple interconnected factors [6,7]:

1. ***Vata Vriddhi*** (aggravation of *Vata dosha*): As the primary pathogenic factor, aggravated *Vata* depletes its seat (*Asthi dhatu*), leading to bone loss.
2. ***Agnimandya*** (diminished digestive fire): Impaired metabolism affects the sequential formation and nourishment of *Dhatus*, including *Asthi*.
3. ***Dhatukshaya*** (tissue depletion): Generalized tissue wasting compromises *Asthi* formation and maintenance.
4. ***Ama*** (metabolic toxins): Accumulation of undigested metabolic waste interferes with tissue nutrition.
5. ***Dhatu-poshan Kshaya***: Impaired nourishment of *Asthi dhatu* from its precursor *Meda dhatu* (adipose tissue).

3.3.3 Conceptual Alignment with Modern Pathophysiology

The *Ayurvedic* pathophysiological framework demonstrates substantial conceptual overlap with modern understandings of osteoporosis:

Ayurvedic Concept	Modern Biomedical Correlate
Vata Vriddhi	Estrogen withdrawal, accelerated bone resorption [12]
Agnimandya	Altered calcium and vitamin D metabolism [5]
Dhatukshaya	Reduced bone formation, impaired osteoblast function [1]
Ashraya-Ashrayi Bhava	RANK/RANKL/OPG pathway dysregulation [1]
Ama (toxins)	Oxidative stress, chronic inflammation [13]
Rajonivritti (menopause)	Estrogen deficiency state [7,12]

Rajonivritti (the postmenopausal phase) is specifically characterized as a period of heightened *Vata* activity, which is posited to play a significant role in bone degradation. Osteopenia and early bone degeneration represent the initial phases of *Asthikshaya*, characterized by progressive loss of bone tissue [7].

3.4 Ayurvedic Therapeutic Interventions

Acharya Charaka states that remedial measures for disorders of *Asthi* consist of *Panchakarma* therapy, *Basti*, and intake of bitter-medicated milk and ghee [6].

3.4.1 *Panchakarma*: The Five Therapeutic Procedures

Panchakarma (five actions) is the cornerstone of *Ayurvedic* detoxification and rejuvenation therapy. For osteoporosis management, specific procedures are emphasized:

***Basti* (Medicated Enema):** *Basti* is considered the prime therapy for *Asthi*-related diseases. As *Vata dosha* predominantly resides in the colon, *Basti* directly addresses the root cause of *Vata* aggravation. Several types of *Basti* have been studied [6,8]:

- ***Majja Basti***: Medicated enema with bone marrow-derived preparations. A clinical trial of 12 patients treated with *Majja Basti* along with *Asthi Shrinkhala* (*Cissus quadrangularis*) pulp capsules yielded encouraging results [11].
- ***Matra Basti***: Oil enema using specific medicated oils. A comparative clinical study evaluated *Vrishyamuladi Taila Matra Basti* and *Shatavari Taila Matra Basti* in 34 patients with *Asthi-Majja-Kshaya* (low bone mineral density). Both groups showed improvement in parameters including *Asthishoola* (bone pain), *Asthitoda* (pricking pain), *Nakhabhanga* (splitting of nails), *Raukshya* (dryness), *Aswapna* (sleep loss), and *Satataruka* (continuous pain) [8].
- ***Tiktaksheera Basti***: Medicated enema with bitter milk preparations [6].
- ***Panchatikta Ksheera Basti***: Enema with five bitter herbs in milk [6].
- ***Dashmool Majja Siddha Sneha Basti***: Enema with medicated oil prepared from ten roots and bone marrow [8].

***Poorva Karma* (Preparatory Procedures):** These include *Snehana* (oleation internal and external) and *Swedana* (sudation/fomentation) to prepare the body for elimination [6].

***Abhyanga* (Therapeutic Massage):** Oil massage using specific medicated oils penetrates deep tissues, nourishes *Asthi dhatu*, and pacifies *Vata* [14].

***Sarvang Swedan* (Therapeutic Steam):** Fomentation following massage enhances circulation and facilitates toxin elimination [14].

Shashtik Pinda Sweda: A specialized form of fomentation using boluses of medicated rice, particularly beneficial for building bone tissue strength [14].

***Upanaaha* (Medicated Bandaging):** Provides structural support and aids healing, particularly in cases with fractures or severe bone weakness [6].

***Kizhi* (Medicated Bolus Massage):** Enhances circulation, reduces pain, and promotes absorption of therapeutic oils into deeper tissues [14].

3.4.2 Herbal Formulations

Several *Ayurvedic* formulations have demonstrated osteoprotective potential:

***Asthi Shrinkhala* (*Cissus quadrangularis*):** This herb has been traditionally used by *Vaidyas* (Ayurvedic physicians) for bone strengthening. A scoping review of studies published between 2014 and 2024 found that *Cissus quadrangularis* can contribute to slowing bone loss by influencing bone turnover markers, particularly reducing serum osteocalcin levels. Its anti-inflammatory effects were noted to reduce pain and enhance mobility in osteoporosis patients. Ethnobotanical evidence supports its traditional use in bone healing, especially in resource-constrained regions. However, effects on bone mineral density showed mixed results [9,11].

Lakshadi Guggulu: A classical calcium formulation for correcting bone metabolic disorders, facilitating fracture repair, treating joint dislocations, and providing analgesic and anti-inflammatory effects. Its modified form, *Pravalyukta Lakshadi Guggulu* (with coral calcium), is being evaluated for enhanced anti-osteoporotic activity [23].

Vyoshadhya Gutika Guggulu: Used as an oral follow-up to *Basti* therapy in clinical trials at a dose of 1g twice daily for 30 days [8].

***Panchatikta Ghrita* (bitter medicated ghee):** A classical formulation studied as add-on therapy to vitamin D3 and calcium supplements in patients with osteopenia. The study demonstrated that *Panchatikta Ghrita* slows bone degeneration processes through stabilizing effects on bone-specific biomarkers, indicating potential usefulness as a preventive agent [19].

Ostoact Tablet: A traditional *Ayurvedic* preparation evaluated in an ovariectomized rat model of postmenopausal osteoporosis. The study demonstrated activity in improving postmenopausal osteoporosis through regulation of the RANKL/OPG pathway [22].

Shilajit: An *Ayurvedic* mineral-herbal preparation. A randomized, double-blind, placebo-controlled trial demonstrated that *Shilajit* extract reduces oxidative stress, inflammation, and bone loss, dose-dependently preserving bone mineral density in postmenopausal women with osteopenia [20].

Piper longum: Investigated in combination with mesenchymal stem cells for glucocorticoid-induced osteoporosis, showing highly effective reversal compared to controls [21].

3.4.3 *Rasayana* (Rejuvenation) Therapy

Rasayana therapy aims to rejuvenate tissues, enhance immunity, and slow the aging process. For osteoporosis, *Rasayana* formulations nourish *Asthi dhatu* and improve overall tissue metabolism. *Vatashamak* (Vata-pacifying) *Rasayanas* are particularly relevant [6,14].

3.4.4 Dietary and Lifestyle Modifications

Acharya Charaka emphasizes that *Ahara* (diet) and *Vihara* (lifestyle) are fundamental to prevention and management [6,14].

Dietary Recommendations (*Ahara*):

- ***Vata*-pacifying diet**: Warm, nourishing, easily digestible foods [14]
- **Calcium-rich foods**: Milk, ghee, sesame seeds, leafy greens [14]
- ***Madhura Rasa* (sweet taste)**: Foods with sweet taste increase the earth element, beneficial for bone tissue [6]
- **Specific foods**: *Kulatthi* (horse gram), *Shunthi* (ginger), *Rasona* (garlic), *Munga* (green gram), *Kushmanda* (ash gourd), and fruits like pomegranate, mango, and grapes help maintain bone density and vitality [14]
- **Adequate protein**: Easily digestible protein at each meal [14]
- **Vitamin D**: Sensible sun exposure and dietary sources [14]

Lifestyle Recommendations (*Vihara*):

- **Regular routines**: Consistent meal times, sleep schedules, and exercise [14]
- **Weight-bearing exercise**: Regular physical activity [14]
- **Posture**: Maintaining proper posture, avoiding overexertion [14]
- **Stress management**: Meditation and *Pranayama* (breath control) [14]
- ***Abhyanga* (self-massage)**: Daily oil massage to pacify *Vata* [14]

4. Discussion

4.1 Integrating Ayurvedic and Modern Perspectives

The conceptual alignment between *Ayurvedic* pathophysiology and modern biomedical understanding of osteoporosis is striking. *Vata Vriddhi* as the primary pathogenic factor in *Asthikshaya* corresponds to the accelerated bone resorption driven by estrogen deficiency and RANKL/OPG dysregulation [1,6,12]. *Agnimandya* parallels altered calcium and vitamin D metabolism [5]. *Dhatukshaya* reflects the net bone loss from uncoupled remodeling [1]. The *Ashraya-Ashrayee Bhava* relationship between *Vata* and *Asthi* finds a molecular correlate in the RANK/RANKL/OPG pathway, where osteoblasts (forming *Asthi*) regulate osteoclast activity (mediated by *Vata*-like catabolic forces) [1,6].

The gut-bone axis, an emerging frontier in osteoporosis research, resonates with the *Ayurvedic* emphasis on *Agni* (digestive fire) and the gut as the seat of *Vata* [17,18]. The recognition that gut dysbiosis influences bone metabolism through immune pathways validates the *Ayurvedic* principle that digestive health is foundational to tissue health, including *Asthi dhatu* [6].

4.2 Evidence for Ayurvedic Interventions

The evidence base for *Ayurvedic* interventions in osteoporosis, while growing, remains limited by methodological constraints. Most studies are small, open-label, or non-randomized. However, several observations merit attention:

Clinical efficacy: *Basti* therapies, particularly *Majja Basti* and *Matra Basti* with various medicated oils, have shown consistent improvement in symptom scores (bone pain, joint laxity, sleep disturbance) and, in some studies, stabilization of bone mineral density [8,11].

Herbal osteoprotection: *Cissus quadrangularis* demonstrates anti-inflammatory and osteogenic properties [9]. *Lakshadi Guggulu* has a long history of use in fracture repair [23]. *Panchatikta Ghrita* shows stabilizing effects on bone biomarkers [19]. *Shilajit* has robust evidence from a randomized controlled trial for preserving bone mineral density [20].

Mechanistic insights: Preclinical studies demonstrate that *Ayurvedic* formulations can modulate the RANKL/OPG pathway, reduce oxidative stress, and exert anti-inflammatory effects mechanisms directly relevant to osteoporosis pathogenesis [22].

4.3 Challenges and Limitations

Several challenges must be addressed for meaningful integration:

Standardization: *Ayurvedic* formulations vary in composition, preparation methods, and quality. Standardization of active principles and dosages is essential for reproducible clinical research [6].

Clinical trial design: High-quality, adequately powered, randomized controlled trials with fracture outcomes as primary endpoints are needed. Most current studies use surrogate outcomes (bone mineral density, biomarkers, symptom scores) [9].

Safety and interactions: The safety profile of long-term *Ayurvedic* therapy and potential interactions with conventional medications require systematic investigation [5].

Integration models: Optimal models for integrating *Ayurvedic* and conventional therapies, whether sequential, adjunctive, or selective based on patient characteristics, remain to be defined [10].

4.4 Implications for Clinical Practice

Despite these limitations, several practical applications emerge:

Prevention: *Ayurvedic* lifestyle and dietary recommendations, *Vata*-pacifying diet, regular exercise, stress management, and daily oil massage align with and extend conventional osteoporosis prevention strategies [14].

Symptom management: For patients with bone pain, joint stiffness, and sleep disturbances, *Ayurvedic* interventions may offer adjunctive benefits when conventional analgesics are insufficient or poorly tolerated [8].

Adjunctive therapy: In patients with bisphosphonate intolerance or contraindications, selected *Ayurvedic* interventions may provide complementary osteoprotection [19].

Low-resource settings: In regions where conventional pharmacotherapy is inaccessible or unaffordable, *Ayurvedic* herbal preparations may offer a practical alternative [9,14].

4.5 Future Directions

Future research should prioritize:

1. **Mechanistic studies**: Elucidating the molecular pathways through which *Ayurvedic* interventions modulate bone remodeling, including effects on the RANKL/OPG pathway, Wnt signaling, oxidative stress, and the gut-bone axis [1,17].
2. **High-quality clinical trials**: Randomized controlled trials with fracture outcomes, adequate sample sizes, and long-term follow-up [10].
3. **Comparative effectiveness research**: Comparing *Ayurvedic* interventions with standard pharmacotherapy and evaluating combination approaches [5].
4. **Pharmacovigilance**: Systematic monitoring of adverse events and drug-herb interactions [4].
5. **Standardization**: Developing quality control parameters for *Ayurvedic* formulations used in bone health [23].
6. **Prevention studies**: Evaluating *Ayurvedic* lifestyle interventions in populations at risk for osteoporosis [14].

5. Conclusion

Osteoporosis represents a growing global health challenge, affecting hundreds of millions worldwide with substantial morbidity, mortality, and healthcare costs [3]. Modern pharmacotherapy bisphosphonates, denosumab, anabolic agents offers effective fracture prevention but faces challenges of adherence, adverse effects, cost, and accessibility [4,5].

Ayurveda provides a coherent, preventive, and therapeutically rich perspective on bone health through the construct of *Asthikshaya* a *Vata*-predominant state of bone tissue depletion that demonstrates substantial conceptual overlap with modern understandings of osteoporosis [6,7]. *Ayurvedic* interventions including *Panchakarma* (particularly *Basti*), herbal formulations (*Asthi Shrinkhala*, *Lakshadi Guggulu*, *Panchatikta Ghrita*), *Rasayana* therapy, and *Vata*-pacifying dietary and lifestyle modifications offer multifaceted approaches to bone health that address not only the local skeletal pathology but also systemic factors including digestion, metabolism, stress, and inflammation [14,19].

Current preclinical and early clinical evidence supports the osteoprotective potential of specific *Ayurvedic* interventions [9,20,22]. However, high-quality, adequately powered clinical trials, standardization of formulations, and mechanistic studies are needed to translate these insights into evidence-based integrative care [10].

An integrative model combining pharmacological therapy with *Ayurvedic* principles offers a promising pathway for comprehensive osteoporosis management. Such an approach could leverage the strengths of both systems: the targeted, evidence-based efficacy of modern pharmacotherapy and the holistic, preventive, and symptom-management capabilities of *Ayurveda*. As the global burden of osteoporosis continues to rise with population aging, integrating traditional wisdom with modern science may provide the most effective and accessible solutions for bone health worldwide.

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