



**INTERNATIONAL JOURNAL OF
PHARMACEUTICAL SCIENCES**
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: <https://www.ijpsjournal.com>



Review Article

Advances in the Prevention and Management of Osteoporosis: A Review Article

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ARTICLE INFO

Published: 11 Aug 2026

Keywords:

Osteoporosis, Bone Mineral Density, Fragility Fracture, Bisphosphonates, Denosumab, Romosozumab, Prevention, Bone Health.

DOI:

10.5281/zenodo.21892768

ABSTRACT

Osteoporosis is a chronic skeletal disorder characterized by reduced bone mass and deterioration of bone microarchitecture, leading to increased bone fragility and fracture risk. It is a major public health concern, particularly among postmenopausal women and the elderly. Recent advances in understanding bone biology have led to improved diagnostic tools, novel pharmacological therapies, and comprehensive prevention strategies. This review summarizes current knowledge regarding osteoporosis epidemiology, pathophysiology, risk factors, diagnosis, prevention, and recent advances in treatment, with emphasis on emerging anabolic agents, sequential therapy, personalized medicine, and digital healthcare approaches.

INTRODUCTION

Osteoporosis is a systemic metabolic bone disease characterized by decreased bone mineral density (BMD) and impaired bone quality, resulting in increased susceptibility to fractures. According to the International Osteoporosis Foundation, approximately 200 million people worldwide are affected. Osteoporotic fractures, particularly of the hip, vertebrae, and wrist, are associated with significant morbidity, mortality, and healthcare costs.

Advances in diagnostic imaging, understanding of bone remodeling, and development of novel medications have transformed osteoporosis management over the past decade.

Bone Remodeling

Bone undergoes continuous remodeling through coordinated activity of:

- Osteoclasts (bone resorption)
- Osteoblasts (bone formation)

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Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.



- Osteocytes (mechanosensors)

The balance between bone resorption and formation is regulated by:

- RANK/RANKL/OPG pathway
- Wnt/ β -catenin signaling
- Parathyroid hormone (PTH)
- Estrogen
- Calcitonin
- Vitamin D

Loss of estrogen after menopause increases osteoclast activity, leading to accelerated bone loss.

Epidemiology

- Affects over 200 million individuals globally.
- One in three women and one in five men over age 50 experience osteoporotic fractures.
- Hip fractures carry a 20–30% one-year mortality rate.
- Increasing life expectancy is expected to significantly increase osteoporosis prevalence.

Risk Factors

Non-modifiable

- Advanced age
- Female sex
- Postmenopausal status
- Family history

- Caucasian or Asian ethnicity

Modifiable

- Smoking
- Excess alcohol intake
- Physical inactivity
- Vitamin D deficiency
- Low calcium intake
- Low BMI
- Long-term glucocorticoid therapy

Table 1. Major Risk Factors

Non-Modifiable	Modifiable
Age	Smoking
Female gender	Alcohol
Family history	Low calcium intake
Menopause	Physical inactivity
Genetics	Vitamin D deficiency

Diagnosis

Bone Mineral Density

Dual-energy X-ray absorptiometry (DXA) remains the gold standard.

WHO Classification:

T-score	Interpretation
≥ -1.0	Normal
-1.0 to -2.5	Osteopenia
≤ -2.5	Osteoporosis
≤ -2.5 + fracture	Severe osteoporosis

Laboratory Investigations

- Serum calcium
- Phosphate
- Vitamin D



- Parathyroid hormone
- Alkaline phosphatase
- Renal function
- Thyroid function

Fracture Risk Assessment

The FRAX tool estimates the 10-year probability of:

- Hip fracture
- Major osteoporotic fracture

Prevention of Osteoporosis

Lifestyle Measures

- Weight-bearing exercise
- Resistance training
- Smoking cessation
- Limit alcohol
- Fall prevention
- Maintain healthy body weight

Nutritional Measures

- Daily recommendations:
- Calcium: 1000–1200 mg/day
- Vitamin D: 800–1000 IU/day
- Adequate protein intake
- Magnesium and vitamin K-rich foods

Table 2. Preventive Strategies

Strategy	Benefit
Exercise	Improves BMD
Calcium	Maintains bone mineralization
Vitamin D	Enhances calcium absorption
Smoking cessation	Reduces bone loss
Fall prevention	Prevents fractures

Advances in Diagnosis

Recent innovations include:

- Trabecular Bone Score (TBS)
- High-resolution peripheral quantitative CT (HR-pQCT)
- Bone turnover markers (P1NP, CTX)
- Artificial intelligence-assisted fracture detection
- Machine learning prediction models

These technologies improve fracture risk prediction beyond BMD alone.

Advances in Pharmacological Management

1. Bisphosphonates

Examples:

- Alendronate
- Risedronate
- Ibandronate
- Zoledronic acid

Advantages:

- Reduce vertebral fractures
- Long-term efficacy



- First-line therapy

2. Denosumab

Mechanism:

- Human monoclonal antibody against RANKL.

Benefits:

- Potent antiresorptive effect
- Convenient six-month dosing
- Effective in high-risk patients

Limitation:

- Rapid bone loss after discontinuation.

3. Selective Estrogen Receptor Modulators (SERMs)

Example:

- Raloxifene
- Advantages:
 - Prevents vertebral fractures
 - Reduces breast cancer risk

4. Parathyroid Hormone Analogues

Examples:

- Teriparatide
- Abaloparatide

Advantages:

- Stimulate new bone formation
- Improve bone architecture

Recommended for:

- Severe osteoporosis
- Multiple fractures

5. Romosozumab

Newest anabolic therapy.

Mechanism:

- Sclerostin inhibition
- Increases bone formation
- Decreases bone resorption

Clinical trials show rapid BMD improvement and reduced vertebral fracture risk.

Table 3. Comparison of Osteoporosis Drugs

Drug	Mechanism	Fracture Reduction
Alendronate	Antiresorptive	Hip & Vertebral
Zoledronic acid	Antiresorptive	Hip & Vertebral
Denosumab	Anti-RANKL	Hip & Vertebral
Teriparatide	Anabolic	Vertebral
Abaloparatide	Anabolic	Vertebral
Romosozumab	Dual action	Vertebral & Hip

Sequential Therapy

Current guidelines recommend:

High-risk patients:

Romosozumab/Teriparatide → Bisphosphonate or Denosumab

Benefits:

- Greater BMD gain
- Long-term fracture protection
- Sustained therapeutic response



Personalized Medicine

Future osteoporosis care emphasizes:

- Genetic risk profiling
- Biomarker-guided treatment
- Individualized fracture risk prediction
- Precision dosing
- AI-assisted treatment selection

Digital Health

Recent innovations include:

- AI-assisted DXA interpretation
- Smartphone fall-prevention applications
- Wearable gait monitoring
- Telemedicine follow-up
- Electronic fracture liaison services

Emerging Therapies

Current research focuses on:

- Cathepsin K inhibitors
- Stem cell therapy
- Gene editing
- Osteocyte-targeted drugs
- Nanotechnology-based drug delivery
- Biomaterial-assisted bone regeneration

Risk Assessment



DXA + FRAX + TBS



Lifestyle Modification



Calcium + Vitamin D



Drug Therapy



Monitoring



Fracture Prevention

Figure 2. Modern Osteoporosis Management

Future Perspectives

Future osteoporosis management will integrate:

- Artificial intelligence for risk prediction.
- Precision medicine using genomic data.
- Long-acting anabolic agents.
- Improved fracture liaison services.
- Digital monitoring and telehealth.
- Regenerative medicine approaches.

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HOW TO CITE: Bhadange Vaishnavi, Dr. P. N. Kelgoankar, Abdare Manjusha, Magar Disha, Kharat Shreya, Advances in the Prevention and Management of Osteoporosis: A Review Article, Int. J. of Pharm. Sci., 2026, Vol 4, Issue 8, 1925-1930. <https://doi.org/10.5281/zenodo.21892768>

