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Commentary

Bone Turnover: Regulation, Influencing Factors, Disorders, and Clinical Significance Explained

Christoph Beyersdorf*

Department for Orthopedics and Trauma Surgery, Medical Faculty, University Hospital Düsseldorf, Duesseldorf, Germany

DESCRIPTION

Bone turnover is a dynamic and continuous process by which old bone tissue is broken down and replaced with new bone. This biological mechanism plays a crucial role in maintaining skeletal strength, repairing micro-damage, regulating calcium levels, and adapting the skeleton to mechanical stress. Bone turnover occurs through two closely linked processes: bone resorption, carried out by cells called osteoclasts, and bone formation, conducted by osteoblasts. The balance between these two processes determines bone mass and structural integrity, and any disruption in this balance can lead to serious skeletal disorders.

Throughout life, the skeleton undergoes continuous remodeling. In childhood and adolescence, bone formation predominates as bones grow in size and density. Peak bone mass is generally achieved by the late twenties. During adulthood, bone remodeling continues, but the rates of formation and resorption typically reach a balance. However, with aging or under pathological conditions, this balance can shift, often leading to more bone resorption than formation. This imbalance results in decreased bone mass, increased fragility, and a heightened risk of fractures.

The regulation of bone turnover is complex and influenced by a variety of systemic and local factors. Hormones play a central role. Parathyroid Hormone (PTH) regulates calcium homeostasis by stimulating bone resorption to release calcium into the bloodstream when levels are low. Conversely, calcitonin reduces bone resorption. Estrogen and testosterone help maintain bone density by inhibiting bone resorption and promoting bone formation. The drop in estrogen levels after menopause is a major contributor to increased bone turnover and subsequent bone loss in women. Growth hormone, thyroid hormones, and glucocorticoids also influence bone remodeling, either directly or indirectly.

Nutritional status is another critical factor in bone turnover. Calcium and vitamin D are essential for bone health. Calcium is the primary mineral found in bone, and vitamin D facilitates its absorption in the intestines. A deficiency in either nutrient leads to increased bone turnover, with more resorption than formation, ultimately weakening bones. Protein, magnesium, phosphorus, and vitamin K also play supportive roles in maintaining bone integrity.

Mechanical stress and physical activity are important regulators of bone turnover. Bones respond to mechanical loading by increasing bone formation, which is why weight-bearing exercise is beneficial for skeletal health. Conversely, prolonged immobility or lack of physical activity reduces bone formation and accelerates bone loss. This principle explains why astronauts in zero gravity and patients on prolonged bed rest experience rapid decreases in bone density.

Certain medical conditions and medications can significantly affect bone turnover. Osteoporosis is the most well-known disorder associated with increased bone resorption and inadequate bone formation. It leads to porous, fragile bones and a heightened risk of fractures. Hyperparathyroidism, either primary or secondary, results in excessive PTH levels that stimulate bone resorption. Paget's disease of bone involves abnormal bone remodeling with excessive resorption followed by disorganized bone formation, leading to structurally weak bones. Medications such as corticosteroids, anticonvulsants, and certain cancer treatments can impair bone formation or promote resorption, contributing to low bone mass and increased fracture risk.

Bone Turnover Markers (BTMs) are biochemical substances released during bone formation or resorption and can be measured in blood or urine. Common markers of bone formation include osteocalcin, bone-specific alkaline phosphatase, and Procollagen type 1 N-Terminal Propeptide (P1NP). Markers of bone resorption include C-Terminal Telopeptide (CTX) and N-Terminal telopeptide (NTX). BTMs are useful in clinical practice for assessing bone metabolism, monitoring treatment response in osteoporosis, and evaluating metabolic bone diseases. They offer insights into the rate of bone turnover and help guide therapeutic decisions.

Monitoring bone turnover is particularly important in managing osteoporosis. Anti-resorptive medications such as

Correspondence to: Christoph Beyersdorf, Department for Orthopedics and Trauma Surgery, Medical Faculty, University Hospital Düsseldorf, Duesseldorf, Germany, E-mail: hristoph5668@duesseldorf.de

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bisphosphonates and denosumab work by inhibiting osteoclast activity, thereby reducing bone resorption and stabilizing or increasing bone density. Anabolic agents like teriparatide and romosozumab stimulate bone formation. Measuring BTMs before and during treatment can help assess how well the therapy is working and whether adjustments are needed.

In children and adolescents, high bone turnover is normal and reflects the rapid bone growth occurring during development. In adults, especially postmenopausal women and older men, increased turnover is more often associated with bone loss and risk of fractures. Therefore, understanding individual patterns of bone turnover can help predict bone health outcomes and customize prevention or treatment strategies.

Lifestyle modifications can positively influence bone turnover and overall bone health. A balanced diet rich in calcium and vitamin D, regular weight-bearing exercise, avoidance of tobacco, and moderation of alcohol intake all contribute to maintaining a healthy rate of bone turnover. These habits are especially important during critical periods such as adolescence, pregnancy, menopause, and aging, when hormonal changes can shift the balance of bone remodeling.

CONCLUSION

Bone turnover is a fundamental physiological process that maintains skeletal integrity and mineral balance. Its regulation is complex, involving hormonal, nutritional, mechanical, and genetic factors. Disruptions in bone turnover can lead to a range of skeletal disorders, with osteoporosis being the most prevalent. Understanding bone turnover and its markers is essential in the prevention, diagnosis, and management of bone diseases. Ongoing research continues to uncover new insights into the mechanisms of bone remodeling, leading to improved therapies and better outcomes for individuals affected by bone-related conditions.