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PERSPECTIVE

Defining Osteopenias and Osteoporoses: Another View (With Insights From a New Paradigm)

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This article suggests classifying "osteoporoses" by their biomechanical pathogenesis instead of by their severity or their accompanying medical conditions. (A) In a "true osteoporosis," bone fragility would increase to such an extent that normal physical activity would cause spontaneous fractures and/or a bone pain syndrome, mainly affecting the spine; however, falls could also cause extremity bone fractures. (B) In a "physiologic osteopenia," reduced bone strength and "mass" would fit correspondingly reduced physical activities and muscle strength so well that fractures would not happen without falls or other injuries. Those fractures would affect extremity bones more than the spine. (C) In "combination states," features of (A) and (B) would combine variably. (D) "Transient osteopenias" would occur while serious injuries heal. After healing, transient osteopenias usually resolve without treatment, and fractures occur only from injuries. While an osteopenia's severity usually affects the risk of fracture, its pathogenesis could strongly affect the treatment needed for prevention or cure. (Bone 20:385–391; 1997) © 1997 by Elsevier Science Inc. All rights reserved.

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Introduction

Defining "osteoporosis" has troubled clinicians since ~1940.[74] Although currently debated,[57,63] a WHO commission defined osteoporosis as a bone mineral density or content 2.5 standard deviations or more below comparable norms.[49] This article suggests further definitions that depend partly on a new skeletal–biologic paradigm.[7,8,32–36,45,47] The definitions depend on some vital biomechanics that have only been clarified in this decade; thus, earlier definitions could not account for the skeletal–biological paradigm.

Defining osteoporoses as some arbitrarily low bone mass is like defining all anemias as an arbitrarily low hemoglobin; for medical needs, that definition is not enough. It is necessary to know the cause of osteoporoses, since effective treatment depends on it. Ergo, different names are given to anemias with different causes (examples: iron deficiency anemia, sickle cell anemia, aplastic anemia). The definitions below are an attempt to do the same, by assigning different names to osteopenias with different vital-biomechanical causes, and possibly requiring different treatments as well (*Note 1*). The next section summarizes some evidence upon which those definitions depend, using vocabulary and ideas taught in few medical schools, and requiring a *Glossary* and explanatory *Notes*.

Basic Science Background

The Biologic Mechanisms That Determine Bone Strength and "Mass"

Since bone cannot foresee its mechanical usage and typical loads, it adapts its strength and "mass" to its past and present mechanical usage in ways that let it endure that usage for life. Excepting longitudinal bone growth, two sluggish tissue-level mechanisms provide the adaptations.[33,44,55] *Bone modeling* by drifts (not osteoblasts alone) controls most additions of bone strength and "mass," and *bone remodeling* by BMUs (not osteoclasts alone) controls most conservation or losses of that strength and "mass". Threshold bone strain ranges (or equivalent stimuli) can control their responses to mechanical usage [55,73] (Note 2). Strains in or above a *modeling threshold* range switch modeling ON to increase bone strength and "mass." This works best during growth and becomes inefficient in adult compacta. Lesser strains leave this modeling OFF. Where strains stay below a smaller *remodeling threshold* range, "disuse-mode" BMU-based remodeling removes that bone, mainly where it touches marrow. Where strains exceed that range, "conservation mode" remodeling conserves bone strength and "mass." In normally adapted young adults, bone strains should stay in the "comfort zone" between those thresholds (**Figure 1**).[19,36]

A mechanism called the *mechanostat* would orchestrate those responses (Note 3).[31,35,44,73] The mechanostat would oversee the fit of bone strength and "mass" to mechanical usage so bones can endure that usage for life, causing bones to be mechanically competent. Where bone strength and mass become inadequate by the modeling threshold criterion, modeling increases them. Where bone is not needed mechanically by the remodeling threshold criterion, disuse-mode remodeling begins to remove the bone. Equally, one thermostat could control the heating of a house, and another thermostat could control its air conditioning, to keep the temperature in a comfort zone.

For such reasons, changing from normal mechanical usage to disuse turns modeling OFF and disuse-mode remodeling ON to cause an osteopenia. In adults, normal activities and muscle strength turn modeling OFF and conservation-mode remodeling ON to keep existing bone strength and "mass." Changing from normal mechanical usage to hypervigorous usage (as in weight-lifting-type activities) turns modeling ON to increase bone strength and "mass" in children, and turns conservation-mode

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remodeling ON to keep bone strength and "mass" in both children and adults.[36,71]

Muscle Strength, Bone Strength and "Mass," and Aging

The usual maximum mechanical loads on a bone cause the strains that control the above activities. Excepting trauma and jumping from heights, the largest loads are a result of muscle forces (Note 4),[15,55,58] so bone strength and "mass" normally fit their needs. Muscle strength normally increases during growth, tends to plateau in young adults, and tends to decrease progressively after about 30 years of age in most people.[1,16,40,52,67–69] By 80 years of age muscle strength can reduce to about 40% of its young-adult value.[5] Bone strength and "mass" show long-known corresponding age-related changes.[63,71]

Physical Determinants of Bone Strength

The material properties of bone control its strength as a tissue, including its ultimate strength, stiffness, and yield point.[15,55,58] These properties vary little with age, bone, sex, species, and most diseases when compared to the following features. A whole bone's strength depends on the amount of bone tissue in it, and on its outside diameter, shape, cortical thickness, and the distribution of its cortical and trabecular bone. The same amount of bone in a cross section can provide more strength in bending and torque when arranged as a hollow cylinder than as a solid one of smaller diameter.[20–23,55] The falls that cause extremity bone fractures usually apply one-time combinations of bending, torque, and compression loads that the bone never had a chance to adapt to, so fractures can result when, without the injury, no problems would ever have developed otherwise.[21] Since bone strength can vary between unusually strong and unusually fragile, the "fracture threshold" some speak of would become an arbitrary place on that continuum.[63]

Microdamage

Mechanical usage can cause microscopic fatigue damage in bone that progressively weakens it. Some microdamage happens in all of us. Normally remodeling BMUs repair the bone by removing and replacing the damaged bone with new bone (Note 5).[10,30,33,56,64,65] Microdamage probably adds to bone fragility in the true osteoporoses defined below, although some controversy still surrounds that.

Proposed Definitions

True Osteoporosis

Here, a "naturally irreversible osteopenia"[41–43] would accompany such increased bone fragility that the patient's *usual* physical activities (whether or not similar to other people of comparable sex, age, race, and body habitus) cause bone pain, and/or spontaneous fractures or related features that affect the spine much more than extremity bones.[33,34] They include spontaneous compression fractures, "codfishing" of vertebral endplates, and vertebral body wedging, alone or in combinations. Most would happen without obvious injuries, but falls could also cause extremity bone fractures. The spontaneous fractures could stem partly from increased bone microdamage. The mechanical incompetence of bone would reveal impaired adaptations of bone strength and "mass" to muscle strength and mechanical usage, *so a mechanostat disorder must exist.*[33,35] These have been called "symptomatic osteoporoses."

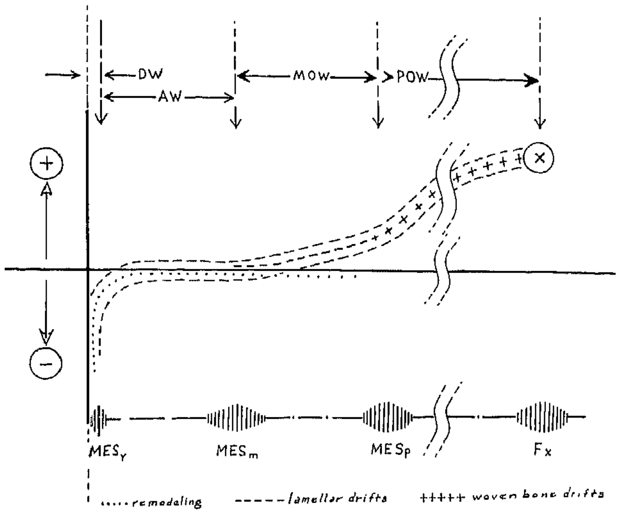

Figure 1. Combined modeling and remodeling effects on bone strength and "mass." The horizontal line at the bottom of this graph suggests typical peak bone strains from zero on the left, to the fracture strain on the right (Fx), plus the locations of the remodeling, modeling, and microdamage thresholds (MESr, MESm, MESp). The horizontal axis represents no net gains or losses of bone strength or "mass." The lower dotted line curve suggests how remodeling removes and weakens bone where strains stay in or below the MESr range, but otherwise begins maintaining bone and bone strength. The upper dashed line curve suggests how modeling begins to increase bone strength and "mass," where strains enter or exceed the MESm range. The dashed outlines suggest the combined effects. D. H. Carter originally suggested such a curve. At and beyond the MESp range, woven bone formation drifts usually replace lamellar bone formation drifts. Fx = the fracture strain near 25,000 microstrain. At the top: DW = disuse window; AW = adapted window or "comfort zone" as in normally adapted adults; MOW = mild overload window as in growing mammals including children; POW = pathologic overload window.[32] In the nearly flat "comfort zone" or adapted window between the MESr and MESm, bone strength and "mass" change little as typical peak strains change. In children, increasing weight and muscle strength shift bone strains towards the MESm. In most aging adults, the strains shift towards the MESr region, because their muscle strength and bone strains usually slowly decrease. Many studies reviewed by Forwood and Burr[24] and Smith and Gilligan[71] support these observations (adapted by permission from: Frost, H. M. Perspectives: A vital biomechanical model of synovial joint design. Anat Rec 240:1–18; 1994).

Physiologic Osteopenia

In this condition, normal activity would not cause spontaneous fractures or bone pain.[33,34] Fractures would only occur after a fall or other injury, and would affect extremity bones much more than the spine (i.e., Colle's fractures, intertrochanteric and femoral neck fractures, some ankle, humeral surgical neck and femoral supracondylar fractures) (Note 6). Decreased muscle strength and physical activities are the cause of these osteopenias. Here, bone strength and mass would meet the needs of reduced mechanical usage adequately, so the mechanostat should work properly. At least three groups of people could develop such an osteopenia.

(A) Medically healthy but chronically inactive people at any age. In older people this was often called "senile osteoporosis," or sometimes "physiologic osteoporosis." Because of the usual age-related decrease in muscle strength, when compared to their bone "mass" at 25 years of age, over 80% of people over 60 years of age should have a physiologic osteopenia, even if separate effects of aging on bone strength and "mass" also exist.

Table 1. Some conditions that cause muscle weakness and disuse in humans (and related osteopenias)[a]

Asthma	Emphysema	Pulmonary fibrosis
Renal failure	Hepatic failure	Cardiac failure
Malnutrition	Anemia	Polyarthritis
Metastatic cancer	Depression	Stroke
Muscular dystrophy	Multiple sclerosis	Alzheimer's disease
Organic brain syndrome	Huntington's chorea	Myelomeningocele
Lou Gehrig disease	Paralyses	Leukemia
Cystic fibrosis	Still's disease	Alcoholism
Drug addiction	Nursing home residency	Myasthenia gravis

[a]In causing an osteopenia, the relative importance of mechanical disuse, muscle strength, and the biochemical–endocrinologic abnormalities accompanying some of these entries is uncertain, since past studies of the matter did not really evaluate the mechanical usage effects. In the paradigm's view, the mechanical usage and muscle strength effects would dominate most (not all) of the biochemical–endocrinologic effects.

(B) Medically healthy postmenopausal women with no bone problems unless a fall occurs. This could include 90% or so of healthy postmenopausal women.

(C) People at any age with a chronic debilitating disease. **Table 1** lists some examples. These individuals often function in progressive physical disuse, due to weak and easily fatigued muscles, sometimes accentuated by chronic musculoskeletal pain.

The Combination States

Features of the above two conditions could combine variably[33,34] to put "pure" physiologic osteopenias and true osteoporoses at opposite ends of a pathologic–pathogenetic continuum. Combination states may happen more often than pure examples of the above two conditions. Could this partly explain why it took so long to recognize the end states as separate realities? And why debate continues over defining spontaneous vertebral body wedging, and even osteoporosis itself?

Clearly, estimates that 30% of people over age 60 have osteoporosis depend on different criteria than the ones above.[2,4,36,37,49]

Transient Osteopenias

Here, a "naturally reversible osteopenia"[41] develops locally after a severe fracture or other injury, such as a burn.[30,33] When the injury heals and normal mechanical usage resumes, most of the lost bone returns without special treatment. Sometimes called "post-traumatic osteodystrophy" or "disuse osteoporosis," the temporary bone losses in these normal reactions to trauma stem partly from acute disuse, partly from a regional acceleratory phenomenon (Note 7), and partly from an increased remodeling space.[30,41,45,47] Fractures would only follow an injury before the "missing" bone returned.

Comments

On Balance and Falls

Deteriorating balance in most aging adults should explain most falls that cause hip, wrist, and related fractures.[60,72] While some assume that all of these fractures stem from a bone disease, if no problems occur without a fall or other injury, on what basis would one separate these fractures from similar fractures in children and young adults? Is this not another continuum matter, where the risk of a fracture increases as an osteopenia does, while with aging the falls that can cause fractures increase too? Would the real disease here lie in the neuromuscular problems that increase falls?

Parenthetically, very simple exercises can improve the balance of many compliant senior citizens.[34]

What Should Absorptiometry Evaluate?

Most fractures from falls begin in the epiphyseal–metaphyseal cortex of the affected wrist, hip, or other bone. They do not begin in the metaphyseal spongiosa, and seldom in the diaphysis (bone shaft).[21] Then, as has been recently suggested,[22,38,67–69] absorptiometry might begin to evaluate the thickness of the epiphyseal–metaphyseal cortex, its outside diameter, and its effect on the bending strength of a bone. These qualities of the epiphyseal–metaphyseal cortex affect the rectangular and polar moments of inertia that affect how size and shape influence a bone's strength under bending and torque loads, respectively. Such loads contribute to most fractures resulting from falls.

What is Normal?

While "less bone than normal" would apply to people of similar age, sex, race, height, and weight, few existing norms account for the chief influence on bone strength and "mass": muscle strength and mechanical usage. Most norms apply to people who are as active (or inactive) as others of similar age, race, and gender, and most adults do become less active with aging. However, aging laborers who retain more of their youthful muscle strength maintain bone density more successfully than others doing less arduous work.[50,71] Mechanical usage is hard to quantitate, but grip testers or other devices in physical therapy facilities can easily measure muscle strength in humans.

Would two standards of bone strength in osteoporosis definition be useful in the future? One, like the existing WHO standard, would measure an osteopenias' severity.[13,49,71] A new standard might relate bone strength to muscle strength that concerns both the osteopenias' pathogenesis and its severity.[22,38,67–69]

How to Tell True Osteoporoses From Physiologic Osteopenias

Could some test distinguish true osteoporoses from physiologic osteopenias? Comparing a bone's strength (as determined by peripheral quantitative computed tomography) to the strength of the muscles loading it might make that distinction. Various workers have published really impressive early comparisons of this kind.[20–23,67–69] If the above definitions are valid, in true osteoporoses, bone strength indices should lie below the line that

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graphs, for normal people, bone strength on the vertical against corresponding muscle strength on the horizontal. However, in "pure" physiologic osteopenias, the bone strength indices would lie on or near that line.[67]

The Role of Pathogenesis on Choice of Treatment

In true osteoporoses, this article suggests that a mechanostat disorder increases bone fragility out of proportion to a patient's muscle strength and physical activity. In physiologic osteopenias, this article suggests that a normal mechanostat causes an osteopenia proportional to reduced muscle strength and physical activity.

If so, effective prevention or cure of those osteopenias would depend on their pathogenesis. For true osteoporoses, that should involve finding and correcting the mechanostat disorder(s) that prevents developing bone strength and "mass" that fit the needs of muscle strength and physical activities. For physiologic osteopenias, this could require maintaining or increasing muscle strength with exercise and/or drugs, and/or finding drugs that potentiate bone's normal responses to hypervigorous mechanical usage.

To emphasize the matter's importance, encouraging increasing physical activities for physiologic osteopenias should be beneficial because their slow bone–adaptive mechanisms would then function properly, given enough time.[33,34] However, that could worsen the condition of patients with a true osteoporosis, because their disordered mechanostat could not effectively strengthen already too-fragile bones in response to increased activities. Thus, more fractures might occur, probably in the spine.

Fracture Risk Relative to an Osteopenia's Severity and Pathogenesis

With the exception of microdamage, an osteopenia's cause should have little effect on the risk of a fracture, which instead should depend mainly on its severity and one's balance. Severity already helps to distinguish between people who need treatment and those who do not or who need further observation, but it is not clear how severity alone could reveal which treatment was needed.

Conclusion

A new paradigm suggests some ideas about osteoporosis that could cause controversy. Because resolving controversies usually improves understanding in any science, and since "Where everyone thinks alike, little thinking is done. . . .," discussion of this material is welcome. James R. Lowell once remarked that only the dead and fools never change their ideas. Who among us would not wish to postpone both those states as long as possible?

Glossary

Bone "mass." The amount of bone tissue, often estimated by absorptiometry, and preferably viewed as a volume minus the marrow cavity. It does not mean gravimetric mass in the sense used in physics and it is not a wholly reliable indicator of bone strength.[13,22,38] "Mass" in quotes in this text refers to its use in absorptiometry.

BMU. Basic multicellular unit of bone remodeling. In 3 or more months, and in a biologically coupled activation → resorption → formation or ARF sequence, it turns over ≈ 0.05 mm^3 of bone. When it makes less bone than it resorbs, this tends to remove bone permanently. Adult humans may create about 3 million new BMUs annually. A million could function at any moment in the whole skeleton. Originally described in 1964.[27]

Evidence of increased bone fragility. (A) This includes fractures from falls or other injuries that would not fracture normal bones. Such "low energy" fractures affect extremity bones more than the spine. (B) It also includes fractures and related features, or bone pain, caused by normal mechanical usage instead of by injuries. Less common than the first kind, bone fragility affects the spine more than extremity bones.

Mechanical usage. All mechanical forces put on our bones by our usual voluntary activities and work. The largest forces come from muscles, not body weight.

Mechanical competence and incompetence of bone. Sometimes called biomechanical competence (and incompetence). Let "competence" imply that a bone fits and endures its normal mechanical usage well enough to keep that usage from breaking the bone or causing deterioration or pain, and that this competence endures for life. Then, "mechanical incompetence" would mean bone that is painful, fractures, or both, due to usual mechanical usage. Mechanical incompetence would be a feature of true osteoporoses but not of physiologic and transient osteopenias as defined in this article.

Modeling. The biologic processes that produce functionally purposeful sizes and shapes for skeletal organs. Mostly independent resorption and formation modeling drifts perform modeling in bones. A recently perceived bone modeling function adjusts skeletal architecture along with bone strength and "mass" to mechanical usage to keep bone strains below the operational microdamage threshold.[33,46] The modeling threshold strain range mentioned previously (the MESm) may center near 1000 microstrain in most adults. While it is genetically determined, age, drugs, disease, species, and other things might modify its value.

Osteopenia. Less bone than normal for most healthy people of the same age, height, weight, gender, and race. It need not represent a disease. Its definition still involves problems and disagreements discussed elsewhere.[33,63]

Osteoporosis. Like Urist,[74] Riggs and Melton recognized that osteopenias and true osteoporoses as defined recently[34] differ, and suggested the "type I" and "type II" terms to designate them.[63] Still, the distinction between the two seems to confuse some authors. The pathogenetically based terms in this article were suggested at recent hard tissue workshops.[48]

Remodeling. Turnover of bone in small packets by BMUs. While drifts and BMUs create and use what seem to be the same kinds of osteoblasts and osteoclasts to do their work, in different parts of the same bone at the same time the 'blasts and 'clasts in drifts and BMUs can act and respond differently to age, gender, mechanical usage, hormones, vitamins, drugs, calcium, etc. In remodeling's "disuse mode," BMU creations increase, and *completed* BMUs create less bone than normal. In the "conservation mode," completed BMUs tend to equalize their bone resorption and formation, and BMU creations usually decrease (unless increased microdamage increases them). The remodeling threshold strain range mentioned in this article (the MESr) should center near 50–100 microstrain. While the MESr is genetically determined, drugs, hormones, age, disease, species, and other factors might modify its value.

Resorption. Different meanings of this term in the literature cause some confusion. Some authors define resorption to mean net bone loss, and in that sense discuss "antiresorption agents." Others use resorption to mean bone resorption by osteoclasts, and refer to net losses of bone as such and separately. Resorption means resorption by osteoclasts in this text. In that sense, few true "antiresorption agents" exist and they do not include estrogen or presently known and studied bisphosphonates, which are antiremodeling agents that decrease BMU creations. Due to the ARF sequence, resorption reduces global resorption first, and then formation, and it reduces both about equally.

Strain. The deformation or change in dimensions and/or shape caused by a load on any structure or structural material. Special gauges can measure bone strains in the laboratory and in vivo. Loads always cause strains, even if very small. Biomechanicians often express strains in microstrain units, where 1000 microstrain in compression would shorten a bone by 0.1% of its original length, 10,000 microstrain would shorten it by 1% of that length and 100,000 microstrain would shorten it by 10% of that length (and break it).

Strength. The size of the load that, when applied once, usually fractures a bone. Bone's fracture strength (ultimate strength) under compression loading lies near 25,000 microstrain. This corresponds to a stress of about 17,000 pounds per square inch, or 120 megapascals. Bone's strength in fatigue is expressed as the number of loading cycles needed to cause a fatigue fracture at a given level of strain or stress (Note 5).

Stress. The elastic resistance of the intermolecular bonds in a material to stretching by strains. Loads cause strains, which then cause stresses. Three "principal" strains and stresses include tension, compression, and shear. We cannot measure stress directly but must calculate it from other information that often includes strain.

Vital biomechanics. A subfield of general biomechanics. It concerns the mechanically controlled biologic activities that fit a skeleton's architecture, strength, and tissue content to its mechanical usage in ways that let the skeleton endure that usage without breaking, deteriorating, or causing pain, lasting a lifetime.

Notes

Note 1: Why Another Classification?

Classifications of "osteoporosis" by nonmechanical causes already exist (i.e., nutritional, endocrinologic, biochemical, postmenopausal, steroid-induced, juvenile idiopathic, thyrotoxic, etc), as does the WHO classification that focuses on severity. Some facts and inferences suggest that vital–biomechanical causes can also classify them. The facts: bone mainly serves mechanical functions. The adaptive mechanisms described in *Basic Science Background* normally fit bone's strength and "mass" to its usual mechanical usage so bone can endure that usage without breaking or hurting. The inferences: when bone does not serve its mechanical usage in that way, an adaptive-mechanism disorder(s) must cause it. That could help to distinguish osteopenias from osteoporoses. Experienced osteoporosis experts have seen all four conditions described in the *Proposed Definitions* section of this article. Anything new there is the basis for distinguishing osteopenias from osteoporoses.

Bone modeling and remodeling and, in children, longitudinal bone growth and endochondral ossification, adapt bone to its mechanical usage. Given the genome's influence, with the exception of microdamage, those mechanisms determine postnatal bone strength and "mass" at all ages in all osteopenias, osteoporoses, and other medical conditions.[30,33,44–47,55] Most nonmechanical agents (hormones, minerals, vitamins, diet, etc.) can help or hinder the responses of those mechanisms to mechanical usage, but cannot duplicate or replace them.

Note 2. On Bone Strains In Vivo

By 1972, clinical–pathologic evidence suggested (A) modeling drifts can increase bone strength and "mass"; (B) bone strains from voluntary activities control the drifts; (C) the drifts respond to some average of many strains instead of to rare or single ones; (D) a few large strains have far more effect than small ones no matter how frequent; (E) some minimum effective strain (an MES) switches these drifts ON (otherwise they would stay OFF); (F) changing strains, not constant ones, control the process; (G) and modeling cannot exceed some maximal speed; it is rate-limited. While controversial in the past,[29] later studies in many animals including humans have verified all those ideas.[5,8,11,25,50,54,59,73] Present work concerning their values and how to express them is now underway. In those studies, peak bone strains from voluntary efforts achieved ~2000–4000 microstrain in most rapidly growing subjects, but only between ~800–1300 microstrain in most adults.

Note 3. On the Mechanostat

This mechanism orchestrates the adaptations of postnatal skeletal architecture and strength to muscle strength and mechanical usage. Evidence for the existence of the mechanostat is abundant, even though it has not been photographed, weighed, or measured.[31,35] (A) The architecture and strength of bones, joints, tendons, ligaments, and fascia normally fit their mechanical usage in ways that let them endure usage for life, and alike in males and females, growing and adult subjects, small and large subjects, in all mammals from the shrew to the elephant, and in all birds, reptiles, and amphibians. Some mechanism(s) must achieve those things, so "mechanostat" was chosen as the name for the mechanism. (B) Bones, joints, ligaments, tendons, and fascia in a limb paralyzed or otherwise made amyotonic at or soon after birth develop abnormal architectures, strength, and "masses." However, they grow normally in the contralateral limb with normal muscle forces. Because the same blood-borne "messengers" go to both limbs, and their cells have the same genome, mechanical usage effects must explain their differences, the responsible mechanism(s) must lie in the affected cells and tissues, and that mechanism must dominate the effects of most blood-borne agents on postnatal skeletal architecture and strength.[30] (C) Growing experimental data provide numerical values for some mechanostat features, including bone modeling, remodeling, and microdamage thresholds.

Note 4. Muscle Strength

Muscle strength usually increases over 20 times between birth and maturity. For example, between a birth weight of 7 lb. and an adult weight of 200 lb, muscle strength increases over 28 times to overcome the resistance of that adult weight multiplied by the bad lever arms most muscles work against. For that reason, the voluntary longitudinal forces on a football player's femur can briefly exceed five times his body weight during a game.[55,58,70] With the exception of trauma and jumping from heights, muscles, not body weight, put the largest loads on bones.

Note 5. Microdamage (Microscopic Fatigue Damage)

Originally demonstrated in 1960,[26] it was rejected by mainstream skeletal thought until Burr's group proved it was not an artifact.[9] Remodeling repairs it by removing and replacing the damaged bone with new bone, another old idea[28] that was verified later.[10,56] Microdamage increases as the number of load–deload or strain–destrain cycles increase, and as the size of the loads or

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strains increase.[6,10,56,61,64,65,75] It weakens bone without affecting its size, shape, content of tissue, or appearance, so absorptiometry does not detect it. It can reduce bone strength below 20% of normal. Bone has an operational microdamage threshold. The modeling threshold normally lies below it,[33,36] which minimizes stress and spontaneous fractures. If cycled at loads that originally cause 2000 microstrain, bone's fatigue life ≈ 10 million cycles, equivalent to 40 years of normal human physical activities.[12] At loads that originally cause 4000 microstrain, bone's fatigue life falls below 20,000 cycles, the equivalent of two months of such activities. At loads that originally cause 5000 microstrain, bone can fail in less than 5000 cycles. As loads merely double in the 2000–4000 range, microdamage increases over 400 times.[61] At and above this strain or load region, woven bone formation begins to replace lamellar bone formation.[8] Controversial when first proposed,[6] current work concerns this threshold's value and how to express it.

Note 6. On the Causes of Fractures

The osteopenia plus microdamage would cause most of the increased bone fragility in true osteoporoses, viewing trabecular "connectivity" as part of the osteopenia. Falls, usually from poor balance, plus increased bone fragility due to an osteopenia and, sometimes, to increased microdamage, would cause most wrist and hip fractures. The mechanics of the fall also strongly influence if and what type of fracture will occur.[62] A bone "mass" 80% of normal should still have nearly 70% of its normal strength, more than needed for the largest voluntary loads one could put on it.

Note 7. The Regional Acceleratory Phenomenon (RAP)

Infection, injury, and some tumors can accelerate all normally ongoing local tissue processes.[30,33] Normally, this RAP hastens healing and improves local resistance to infection and other challenges. In bone it can last for months. It explains much of the increased bone modeling and remodeling following fractures, surgical procedures, tooth extractions, and the implantation of various devices in bone. It explains bone overgrowth after some children's fractures and other injuries.[14] Because a RAP increases regional bone remodeling, it usually increases bone loss next to marrow. When a normal RAP fails to develop, fracture healing usually retards[76] and an infection can progress alarmingly, as in some diabetics. Pathologic RAPs are a common denominator in Sudek's atrophy, reflex sympathetic dystrophy, and migratory osteoporosis or algodystrophy.[3,18,51,53,66] Recognized in the 1960s,[28] clinicians are just beginning to learn about the RAP and its functions and problems.[17]

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