SCIENCE FRIDAY: BONE HEALTH BASICS

II. "MECHANICAL BASIS OF BONE STRENGTH: INFLUENCE OF BOME MATERIAL, BONE STRUCTURE AND MUSCLE ACTION"
by N.H. Hart, S. Nimphius, T. Rantalainen, A. Ireland, A. Siafarikas R.U. Newton
J Musculoskelet Neuronal Interact 2017; 17(3):114-139

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5601257/

SOME KEY POINTS [material in brackets has been modified or added by Earned Runs]:

"Accrual of bone takes place most rapidly in the teenage years, culminating in the third decade of life to achieve peak bone mass."

"Bone strength …. Is modulated by neighboring muscle as a key osteogenic [bone building] stimulant and modifier of mechanical behavior"

"…bone cells are responsive to local strains expressed in their precise vicinity by routine stresses supplied by activities of daily living…"

"… therefore, the determinants of bone adaptation in response to mechanical load involve all aspects of the strain environment" [including strain magnitude, rate, frequency, and distribution, and the number of loading cycles and rest-recovery periods]

"… all components of the strain environment are interlinked and interdependent, such that they collectively contribute to the osteogenic effect and potency of mechanical loading"

MECHANICAL BEHAVIOR [OF BONE]
"… Bone is structurally complex and hierarchically designed, with diverse arrangements and various layers of biomaterial working co-operatively to meet numerous paradoxical requirements."

"… bones behave and respond uniquely to various loading modalities of differing magnitudes, directions, rates and frequencies. While this relationship between mechanical load and mechanical behaviour is multifactorial; bone strength and stiffness are greatest in the direction where loads are most commonly expressed"

"…bone widens under compression and narrows under tension…"

MINERAL CONTRIBUTION [TO BONE STRENGTH]
"Bones are bi-phasic composite materials, with organic and inorganic components. The interplay between these materials and their relative composition considerably influences

mechanical behaviour and bone strength. Specifically, the degree of mineralisation and porosity (i.e.: apparent density) ultimately determines the quality of bone material, and … [its] ultimate strength.

- "Mineralisation refers to the deposition [primary phase] and maturation [secondary phase] of mineral content within bone…"

    - "Sequentially, newly deposited bone begins to rapidly mineralise within ~5 to 10 days of creation, generating ~60% of its total mineral content… gradually advancing toward complete maturation and calcification… within ~30 months of initial deposition."

    - "...If mineralisation and crystallinity are too high, bone may become excessively stiff and brittle"

    - "...If mineralisation and crystallinity are too low, bone may become fragile and weak"

    - "…thus, a presently undefined, yet evidently optimal ratio of organic-to-inorganic material [is associated] with bone strength and mechanical competence."

- "Porosity represents the prevalence, magnitude and distribution of pores within the bone matrix, which characteristically differs between macroscopic tissues" [cortical versus trabecular bone types].
    - [Trabecular bone ~50 to 90% porous]: "porosity is a prominent and purposeful architectural feature"
    - [Cortical bone ~5 to 10% porous]: porosity is "minimal in quantity and size under normal circumstances"

    - "The functional merit of porosity in trabecular and cortical bone is provided at the expense of strength, with small increases in porosity equating to disproportionately large decreases in bone mass and density, the major clinical feature of bone degeneration from ageing, disuse or disease."
    - "Trabecular bone is rapidly affected by increased porosity; resulting in progressively thinner, disconnected and separated trabeculae"
    - [Cortical bone weakening] "is also predominated by increased porosity, resulting in loss of stiffness and reduced load tolerability"
    - "... [increased porosity] of trabecular and cortical bone rapidly compromises mechanical integrity, accounting for ~90% and ~75% of strength loss during ageing respectively.

"Density is the product of mineralisation and porosity, expressed as mass per unit of volume. Specifically, the amount of mineral content per volume of bone [mineralization], and its ratio of void volume to total volume [porosity] respectively combine to establish apparent bone mineral

density.

"Bone mineral density (BMD) [traditionally areal BMD] is a frequently used surrogate measure of mechanical competence and bone strength [bone quality] …"

- to establish fracture risk;
- to diagnose osteopenia and osteoporosis
- to quantify interventional efficacy of preventative and remedial programs.

[However] "all measures of bone mineral density [BMD] inherently neglect structural properties of bone [architecture, morphology, geometry], which substantially influences mechanical behaviour, and greatly contributes to bone strength and fatigue resistance."
…"it is only one of several determinants of bone and should therefore form part of a wider investigative framework which includes structural quantities".

STRUCTURAL CONTRIBUTION [TO BONE STRENGTH]

"Bone has unique …properties which specifically and functionally adapt to routine mechanical loads in order to enhance bone strength and stiffness in the absence of increased bone mass."

- [bone] modifies its structure by adjusting its size (thickness and diameter), shape (contour and dimensions) and architecture (alignment and distribution) …"

MUSCULAR CONTRIBUTION [TO BONE STRENGTH] [**Note: important to athletes!!!]**

"Muscle and bone are inextricably linked by anatomical, mechanical, metabolic and pleiotropic [more than one effect of a gene] functions.

- Anatomically, muscle transforms and mobilises skeletal segments into an interlinked system of levers via tendinous junctions.
- "Mechanically, muscle exerts contractile forces onto the skeleton in order to effectuate movement,"; [muscle supplants gravity as a being a more important stimulant of bone].

- "Metabolically", [hormone signaling between muscle and bone allows] "release of secretory factors capable of modulating each other (muscle to bone; bone to muscle), nearby tissues, and distant organs."

- "Pleiotropically, muscle and bone share several "[genetically determined] "traits, responsive to the same genetic influences and pathways, which if altered, cooperatively contribute to the development of sarcopenia [muscle loss] and osteopenia [bone loss] simultaneously, and may explain co-adaptive anabolic [tissue building] and catabolic [tissue breakdown] responses to [the presence or absence of a] mechanical stimulus."

    - "Adaptation of muscle and bone are interdependent; such that alterations in muscle size, density and strength are linked [in a timely manner] and positively correlated with alterations in bone size, density and strength."
    - "…when immobilised; muscle cross-sectional area, volume and strength significantly reduces after ~5 to 7 days; whereas bone thickness, volume and strength significantly reduces after ~14 to 21 days.

- "…when mechanically loaded, muscle cross-sectional area, length and strength significantly increases after ~20 days; whereas bone diameter, thickness and volume significantly increases after ~40 to 80 days"
  - "The time-course of adaptation is such that genomic and metabolic alterations occur rapidly", [before tissue changes are observed]
  - Muscle changes precede bone changes (~3:1 to 4:1)
  - Losses of muscle/bone occur more rapidly than accrual (~3:1 to 4:1)
    - **exercise-induced long-term gains are rapidly reversed and gradually recovered [!!!]**

- Muscle is a potent osteogenic stimulant
- **Muscle asserts synergistic dominance over bone, such that bone growth or loss is subservient to muscle hypertrophy or atrophy**
- Muscle and bone [co-adapt] together in response to anabolic or catabolic stimuli; highlighting the importance of muscle size and strength as trainable features to enhance and protect bone size and strength.

- "Beyond its osteogenic capabilities,
  - "muscle also acts to mechanically alter the distribution of stress applied to bone
  - muscle derived substances (myokines) that allow "molecular cross-talk [between muscle and bone may have independent effects"

- "Bone mass, material and structure interact with muscle to determine the resultant mechanical behavior and load tolerability of bone to a given loading environment.

  - "… the interplay between loading magnitude and repetition generates a level of musculoskeletal fatigue and structural vulnerability which, in the absence of suitable rest and recovery, will eventuate in traumatic or overuse injury.

  - "… movement quality and efficiency becomes compromised as muscle fatigues, resulting in an altered gait; reduced shock absorption; irregular loading; and abnormal stress distribution, such that higher rates and magnitudes of force undesirably transmit direct to the skeleton"

    In the **absence of recovery** following strenuous activity, accumulative bone fatigue; micro-damage; and eventual bone failure eventuates, highlighting the importance of inserting **rest periods within mechanical loading programs** designed to promote growth or prevent Injury

https://www.ncbi.nlm.nih.gov/pubmedhealth/PMHT0022808/ (bone types)

https://www.livescience.com/12949-cell-suicide-apoptosis-nih.html