The Role of Exercise in Bone Health

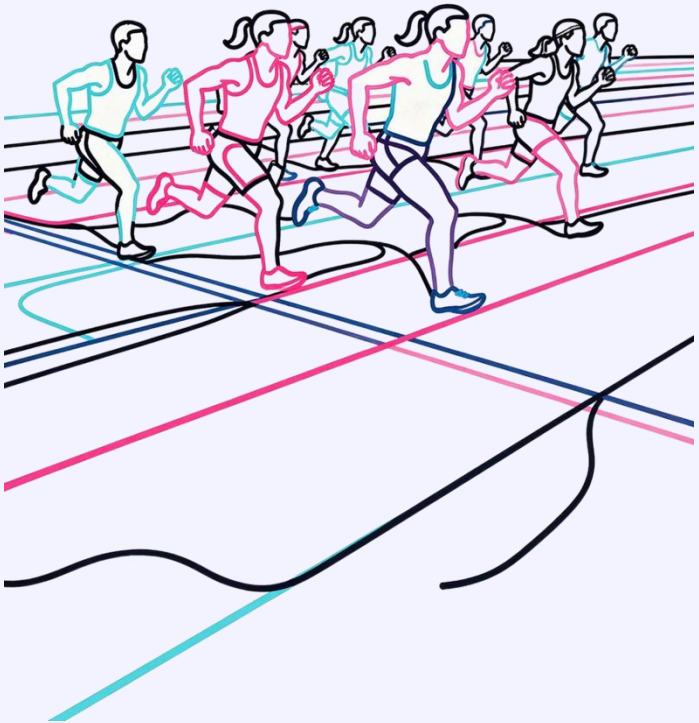
Marci Goolsby, MD

Primary Care Sports Medicine

Medical Director, Women's Sports Medicine Center

Hospital for Special Surgery New York, NY

June 22, 2026



Disclosures

- **I have no relationships to disclose.**

Learning Objectives

1

Mechanism

Explain how exercise influences bone development and remodeling

2

Optimization

Identify exercise characteristics that maximize bone strength

3

Recognition

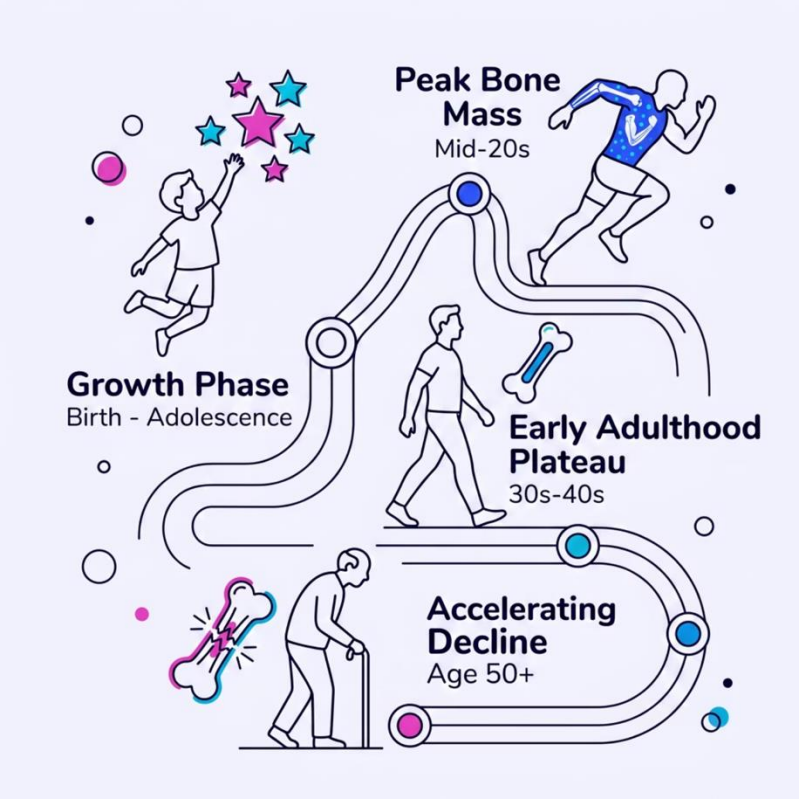
Recognize athletes at risk for impaired bone health and REDs

4

Application

Apply evidence-based approaches to screening and evaluation

Bone Health Through The Ages



90% of peak bone mass

is achieved by the mid-20s — making youth the most critical window

"Osteoporosis is a childhood disease with geriatric consequences."

Peak Bone Mass: The Window of Opportunity

Rapid Accrual

Bone density increases **6–8% annually** during peak pubertal growth — more skeletal mass is gained in puberty than at any other life stage

Lifelong Impact

A **10% greater peak bone mass** may delay osteoporosis onset by up to 13 years, according to modeling studies

Persistent Benefits

Skeletal gains from exercise during growth can persist into adulthood — even if activity levels decline

Take-Home Message: Get kids moving — especially in high-impact, multidirectional sports before puberty ends.

Why Bone Health Matters

1 in 2

Women over 50

will sustain an osteoporosis-related fracture

1 in 4

Men over 50

will sustain an osteoporosis-related fracture

The Long View

Hip fracture carries significant morbidity and mortality — comparable to major cardiovascular events in older adults. Bone health is a lifelong investment, not a geriatric concern.

Exercise Is Medicine for Bone

Exercise is the **ONLY INTERVENTION** that simultaneously addresses every dimension of skeletal health:

Builds Bone

Stimulates new bone formation

Preserves Bone

Slows age-related loss

Builds Muscle

Increases strength and power

Reduces Falls

Improves balance and coordination

Reduces Fractures

Lowers fracture risk across the lifespan

Clinical Pearl: Exercise affects both bone *quantity* (BMD) and bone *quality* (architecture, geometry, and material properties).

How Exercise Builds Stronger Bone: Mechanotransduction

When bone is loaded, a precise cellular cascade drives adaptation.

Mechanical Loading

Exercise, jumping, and impact sports apply force to bone

Bone Deformation & Fluid Flow

Bone bends microscopically → fluid moves through the lacunar-canalicular network

Osteocyte Mechanosensing

Osteocytes sense fluid shear stress via integrins, Piezo1 channels, and Cx43 hemichannels [1,2]

Signaling Cascade

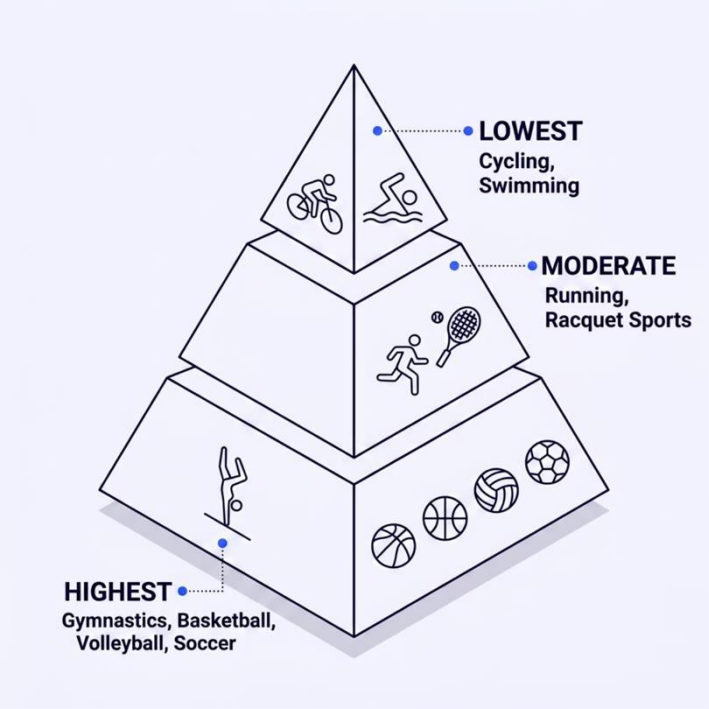
↓ Sclerostin → ↑ Wnt/β-catenin pathway → pro-formation signals [3]

Osteoblast Activation → New Bone

Osteoblasts lay down new bone matrix → increased density, geometry, and strength

What Type of Exercise Builds Bone?

Not all exercise is equally osteogenic. The stimulus depends on the **type, magnitude, and novelty** of loading.



What Makes Exercise Osteogenic?

High Ground Reaction Force

Jumping and impact sports generate 3–10× body weight

Multidirectional Loading

Novel directions prevent skeletal accommodation

Dynamic, Variable Strain

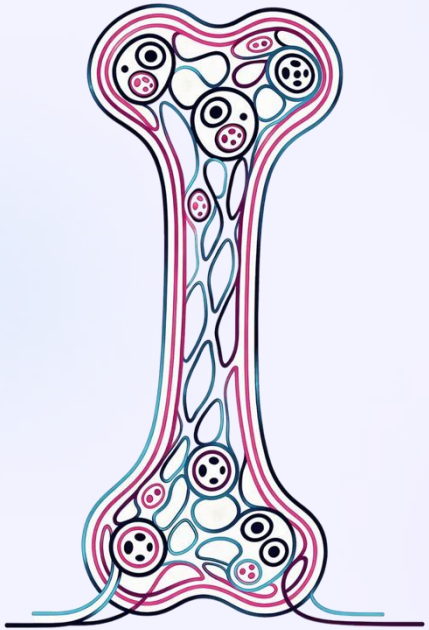
Repetitive monotonous loading is less effective.

Site-Specific Adaptation

Bone strengthens where it is loaded — not systemically

Key Message: Cycling and swimming, despite high cardiovascular benefit, provide minimal osteogenic stimulus.

Bone Strength Is More Than BMD



Beyond the Score

DXA measures areal bone mineral density — a two-dimensional projection that does not fully capture bone's three-dimensional architecture or material properties.

- Exercise improves cortical thickness, cross-sectional area, and trabecular microarchitecture
- Geometric adaptations can substantially increase mechanical strength with modest BMD changes
- HRpQCT and QCT better characterize bone quality but are not routine clinical tools

Strength gains exceed BMD gains

Exercise improves bone geometry and structural strength beyond what DXA measures alone.

Exercise Across the Lifespan

Skeletal goals — and the exercise strategies to achieve them — shift at every stage of life.

1

Children & Adolescents

Build peak bone mass through high-impact, multidirectional play and sports

2

Young Adults (18–35)

Maximize and consolidate skeletal strength with resistance training and impact loading

3

Middle Age (35–65)

Maintain bone mass; resistance training and weight-bearing activities remain essential

4

Older Adults (65+)

Prioritize strength, balance, and functional training to reduce falls and fractures

The Athlete Paradox

When More Exercise Does Not Mean Better Bones

High Energy Availability ✓

Adequate fueling supports skeletal remodeling, hormonal health, and adaptation to training loads

- Normal bone turnover markers
- Healthy hormone levels
- Progressive bone adaptation

Low Energy Availability ✗

Insufficient fueling — even in highly trained athletes — impairs bone health despite heavy exercise volumes

- Suppressed bone formation
- Hormonal dysregulation
- Elevated fracture risk

⚠ **Transition Point:** High training volume without adequate energy intake sets the stage for REDs.

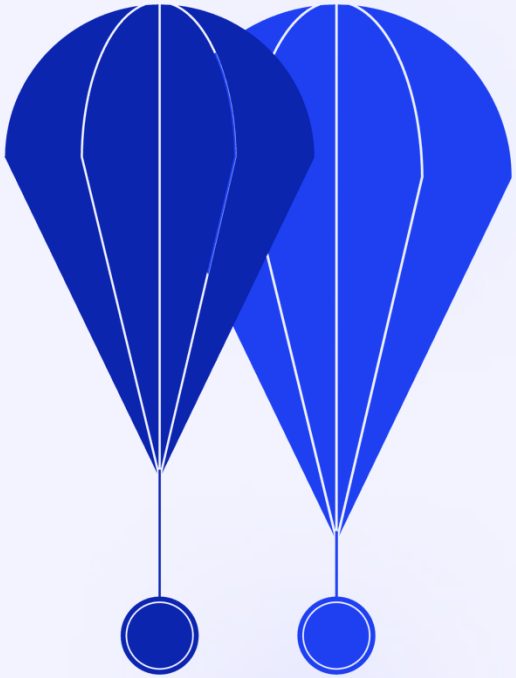
From Female Athlete Triad to REDs

Female Athlete Triad

Disordered eating, amenorrhea, low BMD

REDs Concept

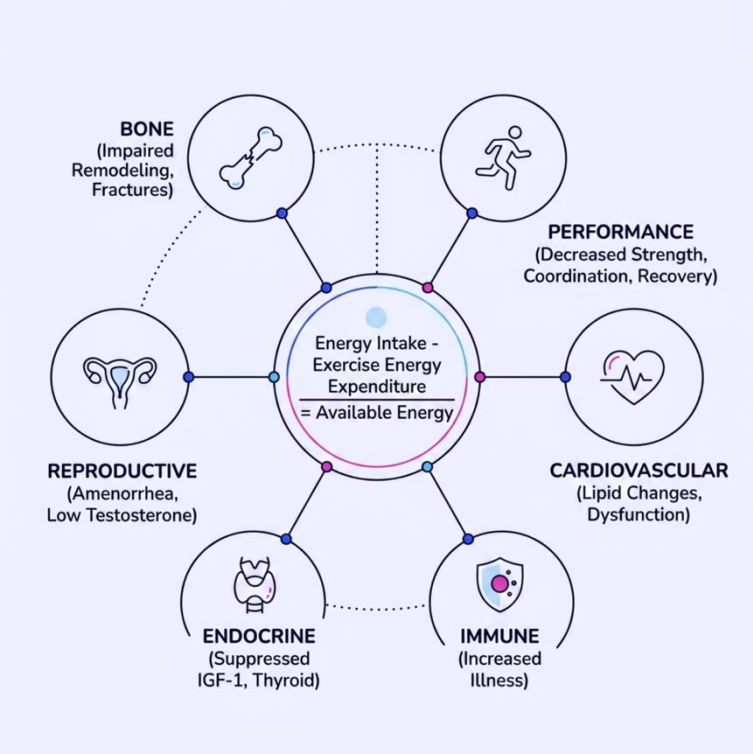
Low energy availability harms multiple systems



The 2023 IOC REDs Consensus Statement broadened the framework beyond the triad: REDs affects both male and female athletes and disrupts at least nine interdependent physiologic systems — with bone as one of the most clinically significant targets.

Understanding REDs

Relative Energy Deficiency in Sport



The Core Equation

Energy Availability (EA) = Energy Intake − Exercise Energy Expenditure

When EA falls below approximately **30 kcal/kg of fat-free mass per day**, compensatory physiologic suppression begins — and bone is among the first systems affected.

⚠ Low EA can be intentional (disordered eating) or unintentional (inadequate fueling around training). Both carry equivalent physiologic risk.

REDs CAT2: Risk Stratification

The IOC REDs Clinical Assessment Tool 2 (CAT2) guides return-to-sport decisions using a traffic-light framework.

GREEN

Full participation. No significant REDs indicators. Continue monitoring at routine intervals.

YELLOW

Participation with monitoring. Mild REDs signs present. Increase surveillance; initiate dietary and behavioral support.

ORANGE

Modified participation. Moderate risk. Reduce training load; multidisciplinary team involvement required.

RED

No participation. High risk — medical stabilization required before any return-to-sport clearance.

Key Message: REDs CAT2 is a validated tool to standardize risk assessment and guide clinical decision-making across settings.

Bone Stress Injuries

A Spectrum, Not a Binary

Bone stress injuries represent a continuum from early stress reaction (bone marrow edema, no cortical disruption) to complete stress fracture.

Common Sites

Tibia, metatarsals, femur, navicular, sacrum, fibula

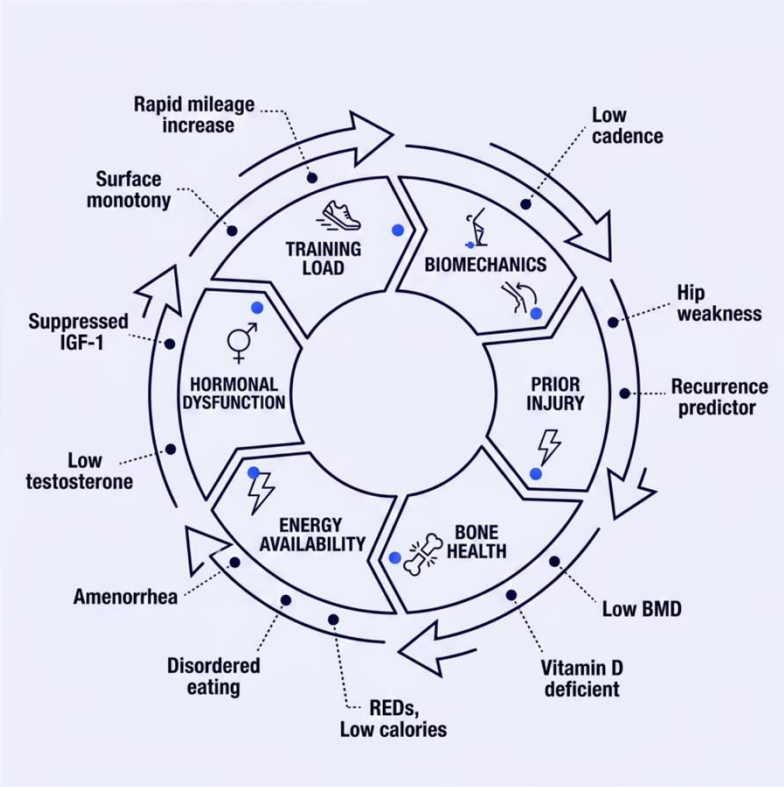
Low-Risk Sites

Tibia (posteromedial), fibula, metatarsals 2–4 — typically heal with activity modification

High-Risk Sites

Femoral neck (tension side), anterior tibia, navicular, 5th metatarsal base, pars interarticularis

Risk Factors for Bone Stress Injury



A Multifactorial Injury

No single risk factor explains bone stress injury — it is the interaction of training stress with individual skeletal vulnerability that determines who fractures.

Clinical Pearl: A **prior bone stress injury** is among the strongest independent predictors of future injury. Always obtain a complete fracture history.

Modifiable factors — energy availability, hormonal status, biomechanics, and training load progression — are the priority targets for prevention and management.

Who Needs Bone Health Evaluation?

PCP Screening Checklist — Ask Every Athlete

Red Flag History Items

- **Stress fracture history** — number, sites, age of first injury
- **Menstrual history** — cycle regularity, age of menarche, duration of any amenorrhea
- **Dietary patterns** — restriction, avoidance, eating disorder history
- **Unintentional weight loss** or persistent fatigue despite adequate sleep
- **Male hypogonadal symptoms** — decreased libido, fatigue, poor recovery

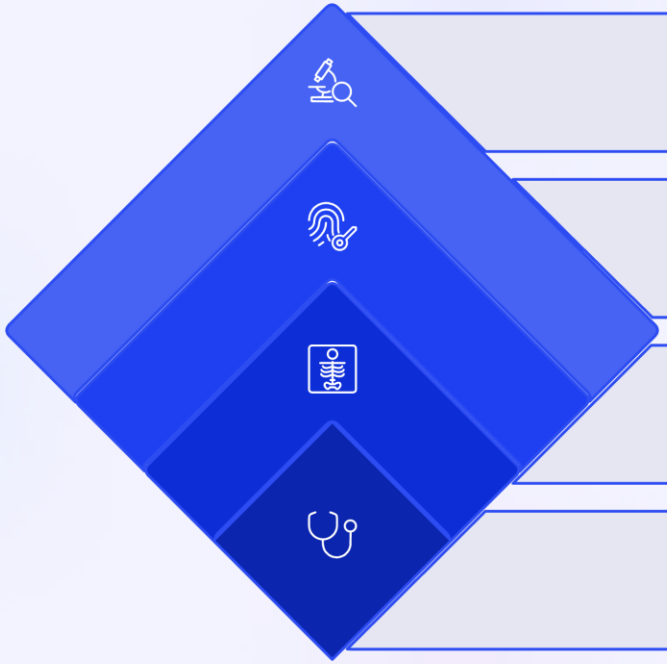
Don't Wait for Symptoms

Many athletes with impaired bone health and REDs are high-performing and appear externally healthy. Proactive screening at the preparticipation evaluation is essential.

Validated Screening Tools

- LEAF-Q (females)
- BEDA-Q (broader populations)
- FAST (Female Athlete Screening Tool)
- Low Energy Availability in Males (LEAM-Q)

When Should You Order DXA?



Interpret Result

Z ⩽ -2.0 = below expected range

Order DXA

Use Z-score for patients <50

Consider DXA

Eating disorder, REDs, low-trauma fracture

Assess Indications

Recurrent BSI, high-risk fracture, amenorrhea

⚠ **Use Z-scores in young athletes, not T-scores.** A Z-score ⩽ −2.0 is defined as "below the expected range for age" per ISCD guidelines and warrants further evaluation and multidisciplinary management.

Exercise Prescription for Bone Health

ACSM and IOC guidelines support age-tailored exercise programming for skeletal benefit across the lifespan.

Age Group	Priority Activities	Frequency / Notes
Children & Adolescents	High-impact activities: jumping, gymnastics, team sports	⩾60 min/day; bone-specific loading 3×/week minimum
Young Adults (18–35)	Resistance training + weight-bearing impact loading	2–3×/week strength; maintain sport participation
Adults (35–65)	Progressive resistance training + moderate-impact aerobics	2–3×/week; emphasize novel, multi-planar movement
Older Adults (65+)	Strength + balance + functional training; Tai Chi, yoga	2–3×/week; fall prevention prioritized; avoid deconditioning

Ensure adequate calcium (1000–1200 mg/day) and vitamin D (1500–2000 IU/day) as the nutritional foundation for any exercise-based bone health program.

Five Take-Home Messages

1. **Exercise is one of the most effective therapies for bone health**

   Both bone quantity and quality benefit — across the entire lifespan

2. **Bone responds best to dynamic, high-impact, multidirectional loading**

   Not all exercise is osteogenic — cycling and swimming provide minimal skeletal stimulus

3. **Peak bone mass is largely set by young adulthood**

   Adolescence is the critical window — inactivity during this period has lifelong consequences

4. **REDs is a major cause of impaired bone health in athletes**

   Low energy availability — not low exercise — is the key driver in athletes who fracture

5. **Primary care physicians play a critical role in identifying at-risk athletes**

   Proactive screening, early DXA referral, and multidisciplinary management prevent long-term harm

Thank You

Marci Goolsby, MD

goolsbym@hss.edu