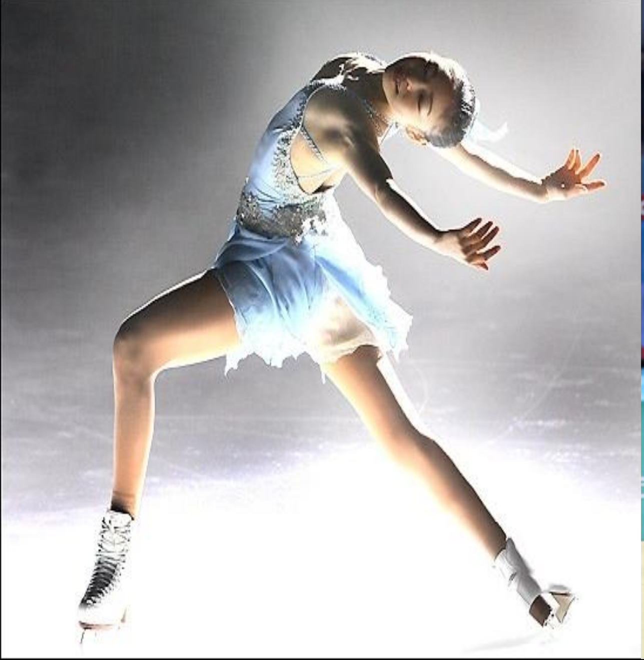  

성장에 대한 운동의 효과

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Growth and maturation

- Growth and maturation are dynamic processes influenced by a variety of **genetic and environmental factors**
  - **growth**: increase in body size
  - **maturation**: biologically mature state
- The main focus of growth: **stature**
  - changes in **body composition, body proportions, skeletal maturation and pubertal development**
- Genetic predisposition ←→ Environmental factors
  - sports activity when exerted **during childhood and adolescence** have a tremendous impact on growth and maturation

Growth and maturation

- Compelling evidence indicating that physical activity affects the skeleton and the BMC and BMD in an **anabolic way**
  - BMC: the amount of mineral measured
  - BMD the amount of mineral measured within the scanned skeletal region but **partially** adjusted for the bone size
- Strong evidence that **moderate exercise** is an important health habit
- Effects of exercise during growth
  - no long-term studies
  - animal study: growth rate? stature?
  - **most studies from athletes**

Physical activity and skeleton

- *Athletes subjected to high load activities had 10%-20% higher BMD compared to the controls (Nilsson BE, Westlin NE.1971)*
- BMC *was* 25%-35% higher among professional tennis players in the dominant arm compared to the nondominant arm (Jones HH, *et al.* 1977)
  - controlled for the **genetic regulation**
- life-long tennis players aged 70-84 yrs had 47% higher BMC in the dominant compared to the non-dominant forearm (Huddleston *AL*, et al. 1980)
  - **at *what* age** period physical activity has **the most pronounced anabolic effects**??

Physical activity and skeleton

- Dominant and non-dominant arm difference were 2-4 times higher if the training was started before than after menarche (Kannus P, et al. 1995)

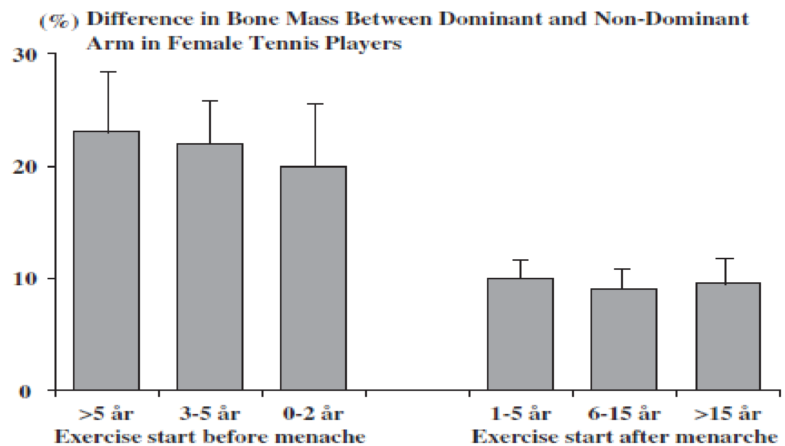


Fig. 1. The mean playing-to-non-playing arm difference in the bone mineral content of the humeral shaft (percentage difference of bone mineral content) according to the biological age at which training was started, that is, according to the starting age of playing relative to the age at menarche. Bars represent 95% CIs. Adapted from Kannus et al. (30).

Physical activity and skeleton

- If exercise is performed **at a high level of activity**, a 10%-20% gain in BMC can be expected (Bass S, et al. 1998)
  - increase in BMC is **only found in loaded skeletal parts**

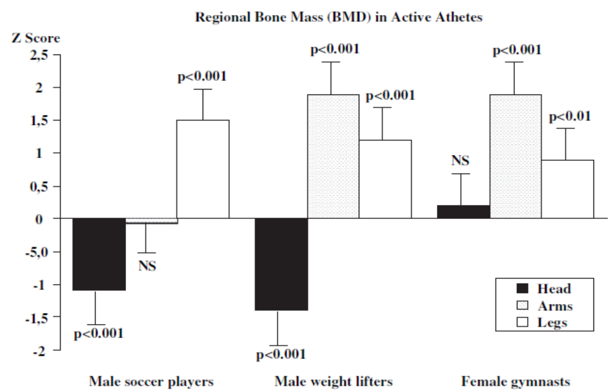


Fig. 2. Bone mineral density (BMD) of the head, the arms and the legs, in active male soccer players, male weight lifters and female gymnasts expressed as *Z* scores (number of standard deviations (SD) above or below age predicted mean). Adapted from Karlsson et al. (31, 34) and Bass et al. (39).

- **Endurance training** do not have higher BMC than controls
  - but, benefits in bone size and skeletal structure that **increase bone strength** independently of the BMC

Which types of exercise?

- The most pronounced **osteogenic stimuli** (Lanyon LE, 1992, Rubin CT, et al. 1984, 1985, Turner CH, et al. 1992)
  - a **dynamic** and **fast** load with **a high magnitude and frequency**
  - a load with unusually distributed strains
- Osteogenic response to mechanical loading **becomes saturated** after a few loading cycles
  - additional loading has limited benefits (**a small number of repetitions** is enough) → the duration of exercise is **of much less importance**
  - bone cell mechanosensitivity seems to **recover** following a period without loading ➔ separating loading into **short bouts with periods of rest**

Which types of exercise?

- **High intensity sports** (squash, tennis, soccer, ice-hockey, badminton, volleyball and weight-lifting) performed on several different occasions during the week are **most effective to improve skeletal strength**
- **Endurance exercise** is **less beneficial** for the skeleton
  - long-distance running (at least weight-bearing activity)

    : minor skeletal benefit
  - cycling and swimming (nonweight- bearing activities)

    : minimal skeletal benefits of biological significance

When is most effective?

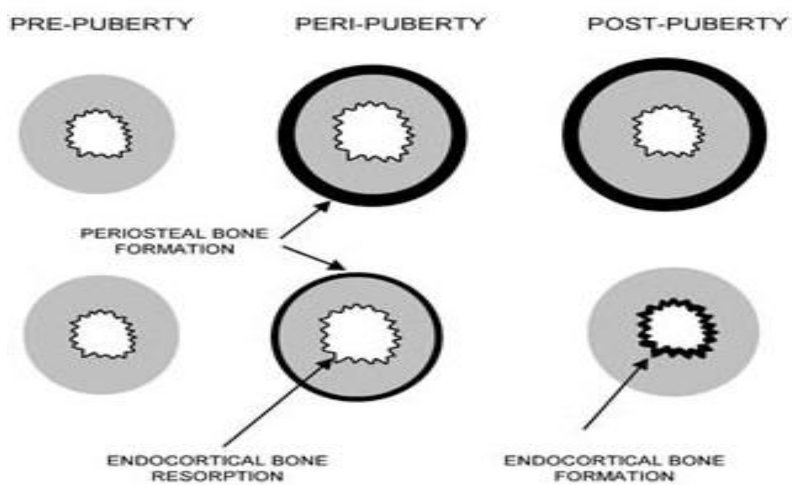
- Pre- and peripubertal period could enhance BMC accrual with a magnitude that would reduce the number of Fx
  - 12 min, 3/wk in 10-yr girls (**pre-pubertal girls**) for 20 months ➔ **4% higher gain** in femoral neck and lumbar spine BMC (MacKelvie KJ, et al. 2004)
  - 80 boys **aged 7-9 years**, 40 min of general physical activity/day (200 min per week) ➔ **3% higher gain** in L3 (Alwis G, et al. 2008)…
- **No increase** in BMC or BMD could be demonstrated after a 6-9 mon intervention period **in post-pubertal children** (Blimkie CJ, et al. 1996, Heinonen A, et al. 2000, Linden C, et al. 2006)
- To enhance the BMD
  - **late pre- and early pubertal period** >> after puberty

Skeletal structure during growth

- Exercise during growth → **bone geometry change** (increase in bone strength, important than BMC alone) (Ahlborg HG, et al. 2003)
- **Bone size** ≒ 10% larger (Bass SL, et al. 2002, Ducher G, et al. 2006)
  - pre-pubertal gymnast > normal children
  - dominant > non-dominant arm in pre-pubertal tennis player
- **Exercise-induced periosteal expansion** and endocortical deposition (thicker cortex)
  - enlargement of bone cross section in response to loading

Skeletal structure during growth

- Pre- to peri-puberty **in male but not in female** tennis players
  - male puberty: periosteal bone formation (androgen, GH, IGF)
  - female puberty: estrogen inhibit periosteal expansion, but stimulate endocortical apposition
  - → similar cortical thickness



Skeletal structure during growth

- Bone structure (bone area or bone size): benefits achieved by exercise during growth (Ruff CB, et al. 1994)
  - **also most effective** for bone structure when initiated **during pre- or early puberty**
- Exercise may preferentially affect the **surface of bone** that is undergoing apposition during growth
  - adding more bone on the **periosteal surface**

Effect of nutrition

- Energy and protein malnourished children have reduced bone size and BMC (Garn S. 1970)
- Beneficial exercise-induced skeletal effects are seen only if the calcium intake is high (**1300 mg/day** in growing individuals) (Bass SL, et al. 2007)
- *After cessation of the extracalcium,* all BMC *benefits were lost after* 12 months *while the structural* benefits remained (Binkley N, et al. 2004)
- **Optimal beneficial skeletal effects are dependent on adequate nutrition**

Intensive physical training

- Growing concern regarding the influence of stress and intensive physical training
    - beginning at an early age, many hours of intense training and competitions at a high competitive level
- Individual sports exert **unique influences** on growth
    - depending on the sport-related specific character, technical skills and training methods and the stage of growth and sexual maturation of the individual athlete
    - complex → approached with extreme caution

Somatic growth in athletes

- Adult final height and the rate of growth are greatly influenced by **genetic factors**
  - final height between monozygotic twins <3cm
  - final height between dizygotic twins ≒ 12cm
- Final height is best correlated to target height
  - TH (boys)= $(FH+MH+13)/2+4.5 = MPH+11 = 44.5+0.376 \times FH+0.411 \times MH$
  - TH (girls)= $(FH+MH-13)/2+4.5 = MPH-2 = 47.1+0.334 \times FH+0.364 \times MH$
- Environment and heredity continuously interact throughout the entire period of growth

Somatic growth in athletes

- Children with similar genetic potential are expected to reach **comparable final height** under optimal environment
  - when exposed to entirely different environment, can **end up with a different adult height**
- **Extensive physical training** may negatively affect growth, especially **during puberty**
  - depends on the type of physical training, age of training initiation, and the intensity of training
  - each sport requires a specific type of exercise and favor a particular **optimal somatotype**

Somatic growth in athletes

- **Period of maximum training during the growth**
  - female gymnasts
    - greatest physical exertion during the **period of pubertal development**
  - male gymnasts
    - maximum training is required **toward the end of puberty**
- **Strict control of energy input with a high energy output**
  - not reasonable to generalize the effects of the activity of each sport on growth
- **Genetic predisposition and preselection**
  - coaches select individuals that best match certain anthropometric criteria for each sport
    - short stature, short limbs, broad shoulders, and narrow hips in artistic gym

Major sports that require intensive physical training

- ***Artistic gymnasts***
  - both female and male *AG were* shorter than their age-related population mean
  - both female and male *AG* showed considerable delay in skeletal maturation
  - target height - actual height SD score: **males** >> females
    - growth process: more susceptible to the detrimental effects of intensive physical training **in males**
  - genetic predisposition to growth was altered (not disrupted) (although final height failed to meet their genetic predisposition)

➔ evidence for **growth attenuation** in *AG*

Major sports that require intensive physical training

- **Rhythmic gymnasts**
  - taller and thinner than average for age
  - growth **continued up to the age of 18**

    (linear growth in normal girls ends by the year of 15)
  - **genetic potentials exceeded**: final adult height is **higher than the genetically determined target height**
  - genetic predisposition and preselection: remain the main driving force for the catch-up growth

Major sports that require intensive physical training

- Growth in gymnasts
  - **delay in skeletal maturation** both in AG and RG
    - probably **multifactorial**
    - low serum sex steroids (delayed puberty), lower GH secretion, disturbance in insulin-like growth factor homeostasis
    - **psychological** stress, modifications in **nutrition**
    - **overuse lesions** of growth plates (esp. lower extremity)
  - deterioration of growth potential in AG (male > female)
  - genetic predisposition to growth was not only preserved, but even exceeded in RG

Major sports that require intensive physical training

- No deterioration of growth was reported in all other sports
- Swimmers: height above the population mean
  - preselection bias by trainers, high energy input
  - no impact of regular intensive physical training on the final height of female swimmers and tennis players (Erladson, M.C, et al. 2008)
- Distance runners
  - mean height approximates the reference medians
  - height velocities are similar to age and sex-specific population means (Eisenmann, J.C. & R.M.Malina, 2002)

Major sports that require intensive physical training

- Tennis players (Sanchez-Munoz, C. et al. 2007)
  - taller top ranked players compared to lower ranked player
  - the influence of preselection bias
- Wrestlers: growth rate was normal (Housh, T.J, et al, 1993)
  - a lower growth rate was observed during the sport season followed by a catch-up growth during the non training season
- Girls training for 12 hr/wk in sports for 4 years during puberty, revealed no difference in height velocity compared to the population means (Geithner, C.A, 1998)
  - rather, a tendency toward **a slightly later peak height velocity**

Major sports that require intensive physical training

- Intensive physical training and athletic performance at high level did **not negatively affect somatic growth in all sports** not requiring **strict dietary restrictions** leading to energy imbalance
- Attention should be drawn to elite AG of both sexes

Pubertal development

- Puberty is a dynamic period of development with rapid changes in body size, shape, and composition
  - the onset of puberty corresponds to a specific biological age

    :bone age rather than chronological age (Rogol, A.D, et al. 2000)

    :bone age -13 years (boys), 11 years (girls) (Tanner, J.M. et al.1975)

- Prolonged intensive physical training ➔ a significant delay in bone age ➔ delayed pubertal development
  - genetic predisposition and variation among individuals should always be considered

Pubertal development

- Delayed pubertal development and sexual maturation in a variety of sports
  - gymnastics, dancing, and long-distance running…
  - determined by the type, frequency, intensity, duration of exercise
  - **strict dietary restrictions** that result in higher energy expenditure
  - delayed menarche **in the high competitive level**
    - Olympic level <<club level
    - training less than 15 hr/week: no menstrual delay
  - prolonged prepubertal stage and shifted pubertal development (normal progression rate: 1.96 ± 0.93 years (mean±SD)) to a later age

Pubertal development

- Major factor for the delay: low body weight (energy deficit)
  - sports requirements for a thin somatotype
  - reduction in adipose tissue mass → decreased estrogen production → delayed breast development and menarche
- The degree of involvement in pubertal development
  - onset, duration, and extent of **energy deficit**
- Intensive physical training and negative energy balance
  - regulating the hypothalamic pituitary set point at puberty
  - prolong the prepubertal stage and delay pubertal development
  - not affecting the duration of the pubertal process

Summary (1)

- Activity at a level that most individuals can perform increases the accrual of bone mineral **during growth**
- **Moderate physical exercise** has beneficial effects on growth
- It is **not necessary** to perform high volumes of exercise to achieve the physical activity benefits on bone
- Starting physical activity **prior to the pubertal growth** spurt stimulates both bone and skeletal muscle hypertrophy to a greater degree
- **Adequate nutrition** must accompany the exercise to achieve the strongest possible skeleton

Summary (2)

- **Extensive physical training** may attenuate growth, especially during puberty
  - combined effects of age of exercise onset, intensity, frequency, duration
- **Strict control of energy** consumption, combined with a high-energy expenditure
  - delay in skeletal maturation → deterioration of growth potential
  - **no deterioration of growth in all other sports** not requiring strict dietary restrictions
- Intensive physical training and negative energy balance
  - prolong the prepubertal stage and delay pubertal progression