

Bone growth and exercise studies: The complications of maturation

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Keywords: Peak Bone Mass, Maturation, Growth

The establishment of an optimum level of bone mineral during the years of growth, when modeling is superimposed on growth, is an important consideration in terms of lifelong skeletal integrity. Adult bone mineral status at any time in life is a function of the amount accumulated during the growing years and the amount lost during adult life. Since low bone mineral is associated with fracture risk¹ it is clear that bone mineral accrual during the growing years should be optimized, if possible.

While peak bone mass is largely determined by heredity, which accounts for over 50% of the variance², lifestyle patterns are also involved in a multifactorial state that is requisite for the maximization of bone mineral accrual during the growing years. Specifically, vigorous weight-bearing physical activity represents the best possibility for enhancing the attainment of an optimal level of bone mineral, within genetic limits³.

The potential of weight-bearing physical activity to positively influence bone mineral acquisition during the growing years is a subject of increasing interest. Numerous studies have appeared in the literature over the past few years dealing with this topic. Although there has been some degree of inconsistency in the results of these studies, the available evidence suggests a significant and positive relationship between physical activity and bone mineral accrual during the growing years. Some of the inconsistent results can be attributed to limitations in study design. These include small numbers of subjects, a short duration of intervention and the difficulty in accurately assessing normal physical activity pat-

terns in children and adolescents. But by far the greatest problem has to do with the failure to control for the wide range in maturational status for children of the same chronological age. The uneven spread in maturity status in children of the same age creates one of the most difficult challenges facing researchers studying adolescent bone growth.

Variability in the journey through adolescence

During the adolescent years, whole combinations of maturity events take place, which are interrelated and occur in sequence although the timing is highly variable. At any given age, there is a wide variation among children in size, physique, body composition, rate of growth, and timing and tempo of biological maturation. For instance, in boys, peak velocities in lean mass, bone mineral and strength always follow peak linear growth (peak height velocity), in that order. In girls, menarche is coincident with peak bone mass following after peak height velocity and peak weight velocity in that order.

The normal range in the onset of these events is high, for instance, the range of normal for the occurrence of menarche is anywhere from 9 to 17 years of age. This wide variability in the onset of a maturity event is further complicated by the fact that there is also a wide variation in the length of time taken to pass through all the events of adolescence. For example, an early maturing girl can take five years to pass through all the events of puberty, or she may take only 18 months. This is further complicated by the fact that there appears to be no relationship between the onset of puberty and the length of time taken to pass through all the stages of adolescence⁴.

Assessment of maturational status

Chronological age is of limited utility in the assessment of maturity. Other methods of assessment are necessary. Skeletal maturity of the hand and wrist as assessed by X-ray (Greulich-

The authors have no conflict of interest.

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Accepted 1 August 2003

Pyle or Tanner-Whitehouse) represents the best way to measure maturational status, but it is expensive, requires specialized equipment and carries with it radiation safety concerns.

The most obvious feature of biological maturity during adolescence is the appearance of secondary sex characteristics. The first sign is the initial development of the breasts in girls and testes in boys, followed by the appearance of pubic hair. Each of these characteristics go through a series of changes as the child passes through adolescence to maturity. Clinical assessment is considered to be intrusive by adolescents and their parents, and self-assessment, which has been widely used in the bone literature, lacks reliability. Since only five discrete stages have been identified (Tanner Stages), only an approximate classification of maturity can be made⁵.

One maturational landmark that can be identified with reasonable accuracy in girls is menarche, the onset of the first menstrual period. In boys no equivalent observable maturational marker is available, making gender comparisons impossible.

Somatic methods such as determining the age of peak height velocity (PHV) require serial measurements of height surrounding the occurrence of peak. Age of PHV is a commonly used benchmark of maturity status in longitudinal studies of adolescents⁶. It occurs at a maturational point equivalent to 92% of adult stature in both boys and girls. This approach is, however, not suitable to assess maturation from a single observation.

Our group have recently suggested that the relationship between sitting height and sub-ischial height may provide an indication of maturity status. Using the known differential timing of growth in these two body segments a regression equation has been developed to predict the age of PHV, from a one-time measurement of growth, and then using the predicted age of PHV as a maturity indicator⁷.

The Saskatchewan approach

To investigate bone mineral accretion in growing children the Saskatchewan Pediatric Bone Mineral Accrual Study was initiated in 1991. The longitudinal study involved the collection of physical activity and dietary information along with 37 anthropometric growth and maturity measurements taken every 6 months. DXA scans (Hologic QDR 2000) of the total body, lumbar spine and the proximal femur were taken annually. Subjects were followed each year for 7 years from 1991 to 1997, and again five years later (2002/03) when all the subjects had attained adult status.

The parents of all the children eight years and older attending two elementary schools in the city of Saskatoon (population 200,000) were contacted. Of 375 eligible students (ages 8 to 14) the parents of 228 provided written consent (113 boys and 115 girls). To date in the year 2002/03 145 of the initial sample have been retested.

To control for the well documented maturational differences between adolescent boys and girls of the same chrono-

logical age, we determined the age of peak linear growth (PHV) for each individual subject. This gave us a common maturational landmark, and the baseline for comparisons between boys and girls or activity groups became a developmental age baseline (-3, -2, -1, PHV, +1, +2, +3) as opposed to a chronological age baseline (9, 10, 11, 12, 13, 14, 15). A cubic spline fit was applied to the whole year velocity values for each child for each variable under consideration. Bone mineral values or structural values were determined at points on the velocity curves for each variable representing ages 3, 2, 1 years on either side of PHV.

Some findings

The adolescent growth period is a critical time for bone mineral accretion. In the two adolescent years of peak skeletal growth (PHV \pm 1yr) over 25% of adult total body bone mineral content is laid down⁸. This is equivalent to the amount of bone mineral that will be lost from the ages of 50 to 80⁹.

Weight-bearing physical activity is a modifiable determinant of peak bone mineral accrual. We have demonstrated that the growing skeleton responds to increased everyday physical activity by increased bone mineral content¹⁰.

During the adolescent years there is a dissociation between linear growth and bone mineral content. Peak linear growth precedes peak bone mineral accrual by over 8 months in boys and 11 months in girls. This lag time between peak linear growth and peak bone mineral acquisition has clinical significance. Adolescent fracture incidence is at a peak during this period¹¹.

Consistent with the above observation, bone area as measured by DXA also peaks before BMC. Since areal density (BMD) is expressed as the ratio of BMC/Bone Area, this asymmetry between the numerator and denominator of this fraction suggests that BMD is an inappropriate and misleading measure for use in intervention studies with growing children.

The sequence of attaining peak height velocity and peak tissue velocities is similar in both sexes. PHV precedes peak lean mass and peak weight velocity in that order. Peak fat mass and peak BMC velocities occur almost simultaneously and are the latest peak velocities¹². The timing of peak BMC and menarche are coincident¹³.

Using a multilevel modeling approach we have demonstrated that the major contributors to observed gender differences in BMC are for the most part associated with stature and lean mass differences. Although an independent sex effect was evident, the effects were less than the error of measurement leading us to conclude that there is no biologically significant independent difference in BMC between adolescent boys and girls¹⁴.

In our sample, the greatest gain in height occurred during the summer season. Summer velocities accounted for at least 67% of the total yearly growth in boys and 60% in girls. The attainment of peak height velocity and therefore the age of

peak height velocity is a summer season phenomenon for our geographical location¹⁵.

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