Rehabilitation Considerations for the Pediatric and Adolescent Female Athlete

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ABSTRACT

This monograph discusses evidence-based management of the young female athlete across the care continuum, from injury prevention training to injury rehabilitation to safe return-to-play. Growth, maturational, biomechanical, and training-related injury risk factors unique to the young female are highlighted. Common sports-related injuries and conditions sustained by this population are addressed through discussion of injury prevention principles, rehabilitation strategies, and sport-specific considerations. Evaluation techniques, intervention ideas, and return-to-sport decision-making guidance are presented throughout the monograph and the accompanying case studies. The monograph presents 4 case studies highlighting the clinical management of the injured, young female athlete. The first case involves a 14-year-old female softball player attempting to return-to-play following an elbow injury. The second case presents non-surgical management strategies for returning a 17-year-old female to basketball following an anterior cruciate ligament injury. The third case involves an 11-year-old elite gymnast referred to physical therapy for chronic low back pain. The fourth case introduces management strategies for progressing a 13-year-old dancer back to classes following an ankle injury.

Key Words: adolescence, injury, risk factors, sports

LEARNING OBJECTIVES

Upon completion of this monograph, the participant will be able to:

1. Define the young female athlete.
2. Discuss the implications of sports participation on a young female's physical literacy development.
3. Describe growth and maturational changes experienced by the young female athlete throughout childhood and adolescence.
4. Identify growth, maturational, biomechanical, and training-related risk factors for injury among young female athletes.
5. Recognize common acute and overuse injuries sustained by the young female athlete.
6. Understand the principles and key components of injury prevention training for young female athletes.
7. Identify tests, measures, examination, and evaluative techniques used for the diagnosis and assessment of impairments and functional limitations in young female athletes.
8. Select appropriate evidence-based treatment interventions for sports-related injuries and conditions in young female athletes.
9. Identify situations when referral of young female athletes to other health care providers beyond physical therapists may be necessary.

INTRODUCTION

Since the signing of Title IX in 1972, the influx of girls and women into sports of all kinds has been astounding. While female athletes still face the reality of fewer sport opportunities and lower funding than their male peers, more girls and women are participating in sports today than ever before. In fact, the rate of female participation in sport has increased by more than 1000% in the last 50 years.[1] Not only has this growth created opportunities for more females to gain exposure to sports, it has also increased the health and wellness of women and girls throughout the country and around the world. As a result, the emphasis on keeping females healthy and active in their sport endeavors is also stronger than ever. Female athletes have made a name for themselves on the courts, the fields, and the rinks. Unfortunately, they have also made a name for themselves in the medical textbooks and sport medicine clinics - young female athletes.

Due to advances in medicine and research, our understanding of the distinct differences between female and male youth athletes is growing. Differences exist in growth, maturation, and development. Injury patterns vary between populations, often associated with pubertal status and sport participation. Young females benefit from unique instruction, conditioning practices, injury prevention techniques, and rehabilitation timelines compared to males. Young females also experience unique social pressures and environmental barriers. All of these factors play an important role in injury risk, recovery, and rehabilitation for this population. The aim of this monograph is to present these unique characteristics of the young female athlete and guide the reader through special considerations required for optimal health and continued participation in sports and physical activity.

Who Is the Young Female Athlete?

Any pediatric or adolescent female (ages 6-18) who participates in competitive or recreational sport- or exercise-related activity is considered a young female athlete. Young female athletes come in all shapes, sizes, and ability levels. Traditional sports with the most participation opportunities at the high school level among females include track and field, volleyball, basketball, soccer, softball, cross country, tennis, swimming and diving, competitive spirit (cheer), and lacrosse.[1] However, non-traditional sports such as wrestling, rock climbing, Ultimate Frisbee, and surfing are quickly attracting more female youth. Additions of "adventure" sports within the Olympic Games and increased coverage of Paralympic disciplines are also fueling the expansion of options for this

population. A good understanding of the unique demands of a sport is critical for any rehabilitation professional. **Table 1** presents sport-specific demands and common injury patterns for young female athletes. No matter the type of sport or level of competition, participation in sports is frequently associated with numerous benefits for young females. Compared to their non-active counterparts, young female athletes are more likely to experience greater physical and emotional health, higher body esteem, healthier body weight, lower risk of chronic disease, greater academic success, and higher quality of life.[2]

Who Is Participating and Who Is Not?

Up to 47% of females are involved in some kind of organized sport by age 6, and as many as 84% of females participate in organized and team sports throughout childhood and adolescence.[2] While the rising rate of sport participation among young females offers a promising outlook, there are still many girls not engaging in sports-related physical activity. Only 30-40% of young females ages 6-17 in the United States are participating in organized sports on a *regular* basis,[3] a rate that consistently lags that of males by 10 percentage points.

Table 1. Sport-specific Demands and Common Injuries Among Young Female Athletes

Type of Athlete	Example Sports	Sport-specific Demands	Common Injuries/ Conditions
Cutting/pivoting (360° athlete)	Soccer, basketball, lacrosse, Ultimate Frisbee	Cutting, pivoting, landing, sprinting, object manipulation	Lower extremity ligament sprains, muscle injuries
Jumping	High jump, pole vault, jump rope, cheer, volleyball, basketball	Force production and attenuation, technique	Apophyseal injuries, muscle injuries
Collision/combat	Boxing, rugby, martial arts, wrestling, fencing, ice hockey	Force production and attenuation	Fractures, contusions, concussion
Serving/throwing/swinging (overhead athlete)	Volleyball, softball, baseball, discus, shot put, tennis	Object manipulation, technique	Muscular imbalances, upper extremity injuries
Swinging	Golf, softball	Object manipulation, technique	Muscular imbalances, upper extremity injuries
Racquet	Tennis, badminton	Cutting, pivoting, object manipulation, technique	Overuse injuries, muscular imbalances, upper and lower extremity injuries
Accuracy	Archery, bowling	Precision, technique	Tendon injuries, nerve injuries
Aesthetic and performing arts	Dance, gymnastics, diving, figure skating, cheer	Jumping, landing, rotation, extreme range of motion	Hip injuries, ligament sprains, female athlete triad
Strength	CrossFit, weight lifting, power lifting	Technique, power	Muscle injuries, load management injuries
Aquatic	Swimming, water polo, water skiing	Swimming skills, cardiovascular fitness	Overuse injuries, tendon injuries
Endurance	Running, rowing, cycling	Cardiovascular fitness, technique	Overuse injuries, female athlete triad
Winter sport	Ice hockey, skiing, snowboarding	Sliding/skating, adaptation to environment	Fractures, ligament sprains, concussion
Adventure sport	Rock climbing, surfing	Core strength, endurance, adaptation to environment	Apophyseal injuries, fractures
Adaptive	Wheelchair basketball, triathlon, skiing	Strength and mobility, equipment needs	Soft tissue trauma, shoulder injuries
Recreational/cross-training	Yoga, Pilates	Balance, strength, neuromuscular control	Muscle injuries, tendon injuries

Furthermore, only 20% of young females nationwide are engaging in at least 60 minutes of physical activity per day.[4] Certain demographics have more representation in sports than others, including girls in middle/upper classes, those who are White, and those who reside in suburban settings.[1] Unfortunately, many young females of color, those of lower socioeconomic status, and those residing in urban and rural areas often do not have the same opportunities to be physically active, due to lack of access and resources.[1] Up to 24% of girls living in urban settings quit sports by the age of 14, compared to 6% of girls in suburban areas. Females with disabilities, those from immigrant families, and LGBTQ girls are also less likely to participate in sports.[1] Females are 60% more likely than males to stop playing sports by age 14, with "injury" cited as one of the top reasons for dropping out.[2] Physical therapists are well-suited to both care for the young female athlete with a sports-related injury and also foster continued participation in physical activity. Current research has also indicated that participation in sports as a youth may matter more for females than males. Active young females tend to remain more active as young adults than their less active young female counterparts, although this relationship between childhood and adult physical activity levels is not seen among males.[5]

Who Is Researched and Who Is Not?

Females remain significantly underrepresented in sports medicine and exercise science research.[6,7] The absolute number and percentages of female participants used in research studies does not match the growing participation numbers seen in sport. Furthermore, there is a striking paucity of studies on the adolescent female athlete.[8] Therefore, the reader should note that while sports- and rehabilitation-related knowledge of the young female athlete is growing, current practice is still heavily influenced by research conducted on males.

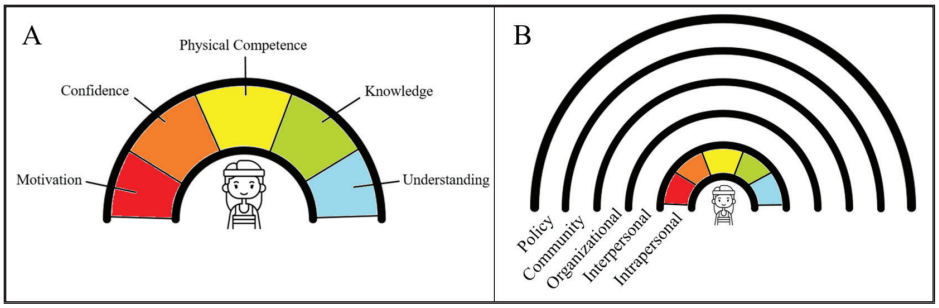
The traditional sex-based biological point of view embedded within much of the available research has informed our awareness of differences in injury risk, injury mechanisms, and efficacy of prevention programs between males and females. However, most of this work does not take into account the developmental environment in which a young female identifies as an athlete (or not). Even before entering sport, females experience gender socialization in the form of gender-biased toys, reduced independent mobility, and lower exposure to motor skill development opportunities (eg, throwing practice).[9,10] The sport training environment often favors males, as is seen with gendered weight room dynamics and low proportion of female coaches. Social norms of what the ideal female body should look like may dissuade young females from prioritizing and pursuing resistance training. Disparities even exist in the rules and equipment requirements of men's and women's sports (eg, male lacrosse players wear a full helmet and face shield, while female lacrosse players only don protective eyewear and soft headgear). Furthermore, young girls may be tempted to only participate in sports that have been deemed socially appropriate for females, such as softball instead of football. Parsons et al[11] hypothesized that these gender-dependent factors may be influencing the high rate of anterior cruciate ligament (ACL) injuries seen among young females, which has often been attributed to biological differences between sexes. Clinicians who work with the injured young female athlete should consider these gender-dependent factors in addition to the sex-based biological traits such as anatomy, physiology, and hormones. A good understanding of a young female's sport and social environments can greatly assist the physical therapist in providing optimal education, interventions, and return-to-play (RTP) decision-making following injury.

Physical Literacy of the Young Female Athlete

The effects of a young female athlete's environment extend beyond just their sports-related injury risk. The built, natural, and social environments in which an individual develops all have the potential to influence lifelong physical activity participation. Environmental factors such as access to good coaching, available play spaces, and geographical location can both positively and negatively affect various aspects of a young female's physical literacy development. Physical literacy, defined as "the motivation, confidence, physical competence, knowledge and understanding to value and take responsibility for engagement in physical activities for life," is considered a determinant of health (**Figure 1**).[12] A physically literate young female is more likely to be a motivated, confident, and proficient mover who enjoys participating in physical activity. Being physically literate at a young age is also thought to be a catalyst for a physically active adolescence and young adulthood.[13]

Despite recent increases in sports participation, a large proportion of the young female population is at risk of physical illiteracy. At one end of the physical activity spectrum are the young females who do not partake in sufficient physical activity. As a result, these youth are at risk of inadequate fundamental skill development, low movement confidence, and are more likely to be overweight or obese. Among those at the other end of the physical activity spectrum are the young females who are spending many hours/week training for a particular sport, at the exclusion of all other modes of physical activity. These sport specializers are also at high risk of physical illiteracy due to inadequate development of movement patterns and muscle groups. If good physical literacy is not attained by an early age (~12 years old), young females may be limited in the physical activities they are able to participate in throughout life. Conversely, sufficient exposure to a wide variety of movement patterns and settings (eg, land, air, water, snow/ice) early in life can promote movement adaptability and creativity, in addition to durability and injury resistance. Physical therapists can support proper physical literacy development among young females by addressing deficits in fundamental movement skill mastery and providing a motivating environment that fosters

Figure 1. Physical Literacy



A, The intrapersonal components of physical literacy. Components encompass the factors within the affective, physical, cognitive, and behavioral domains of the individual. B, Socioecological, systems-level perspective of physical literacy. Factors within each level of the socioecological model influence and are influenced by the individual.

confidence in movement. Furthermore, physical therapists are well-suited to provide education about safe physical activity participation, including the risks of inactivity and early sports specialization. Keeping young female athletes in the game is critical for ensuring health and wellness throughout their lifespan.

UNIQUE CONSIDERATIONS FOR THE YOUNG FEMALE ATHLETE

A growing amount of research is revealing that young female athletes are at higher risk of certain sports-related injuries and conditions compared to their male counterparts. Among the general population, young females sustain the highest rates of ACL injuries.[14] The risk of ACL injuries among young females is almost 1.5 times that of males across all adolescent sports,[15] with the highest incidence occurring between the ages of 14 and 18 years.[14] Patellofemoral pain (PFP) is also disproportionately more present among young females, who are 2-10 times more likely than males to develop symptoms.[16,17] Similar trends are seen for bone stress injuries (BSIs) such as medial tibial stress syndrome and stress fractures of the lower extremity.[18,19] Joint hypermobility is more common among pubertal and post pubertal females,[20] and is thought to contribute to an increased incidence of overuse and joint instability injuries of the hip and knee.[21,22] Research on sports-related concussion indicates that young female athletes have a 1.5 times higher risk of sustaining a concussion during participation in sports,[23] and appear to sustain more severe concussions than young males.[24] Young female athletes are also more likely to present with a combination of decreased energy availability (EA), menstrual dysfunction, and low bone mineral density (BMD), a medical condition known as the female athlete triad.[25]

Injury burden of sports-related injuries during participation in youth sports may also differ between males and females. Among elite young athletes, females have demonstrated a higher average weekly injury prevalence, as well as a higher prevalence of time-loss injuries than males.[26] Overuse injuries are more common among young females.[27] Aside from gendered environmental disparities between males and females, differences in growth, maturation, and development are known to contribute to these sports-related injury patterns unique to the young female athlete. The following sections will provide an overview of the physical changes that may contribute to these distinctive injury risks for the young female athlete.

Growth, Maturation, and Development of the Young Female Athlete

The young body undergoes tremendous changes from the time of infancy through adolescence and into young adulthood. Working knowledge of the growth, maturational, and developmental changes experienced by youth is essential for any health care provider who works with the young female athlete. An understanding of the distinct differences between young males and young females will guide the provider in making developmentally appropriate clinical decisions. **Table 2** provides a summary of potential injury implications as a result of the growth and maturation that occurs during adolescence.

The onset of puberty, or the period of sexual development between childhood and adulthood, can vary among young females due to body composition, race, ethnicity, and environmental factors such as nutrition and participation in a competitive training environment. Gymnasts, ballet dancers, and figure skaters often demonstrate delayed growth spurt and later timing of peak height velocity (PHV), or period of fastest upward growth in stature, compared to other athletes. Young females who participate in rowing, running, and swimming for ≥12 hours/week for an average of 4 years during puberty also demonstrate slight delays in PHV and menarche.[28] However, before females even reach the onset of puberty, changes in the neuroendocrine system mark the beginning of adolescence. During late childhood, the hypothalamic-pituitary-gonadal axis stimulates the release of estrogen from the ovaries, which facilitates the start of the pubertal growth spurt, ovulation,

Table 2. Growth- and Maturation-related Changes and Associated Injury Implications

Growth/Maturation Variable	Changes that Occur During Adolescence	Potential Injury Implications
Stature/standing height	Increase in height >9cm/year during growth spurt; PHV reached by age 12-13	Potential decrease in flexibility during growth spurt
Body mass	Mass gain of 15-20 lbs/year during PWV	Reduced physical performance capabilities during PWV and changes in center of mass location
Skeletal maturity status	Ossification of growth plates; bone length grows prior to gains in BMD	Peak growth plate injuries between 12 and 14 years of age
Bone health	BMD lowest just prior to PHV	Reduced long-term bone health in the absence of adequate BMD accrual during puberty
Body composition	Slowing in the accrual of muscle mass; increase in fat mass	Increased potential for desire to lower energy intake
Hormonal influence	Estrogen, growth hormone, and IGF-1 levels increase, stimulating height growth and reproductive maturation	Improper nutrition and/or excessive training load in late childhood and early adolescence may hinder the effects of hormones responsible for growth and development
Joint laxity	Females demonstrate greater generalized joint hypermobility after the onset of puberty	Decrease in passive joint restraint may affect the type, severity, and incidence of injury
Musculoskeletal system	Only slight increase in muscle mass relative to overall mass and body size	Increases in absolute force production may not match increases in level of play or sport/coach demands
Strength/performance	Plateaus noted in strength and performance of tasks such as throwing and jumping	Decreased strength reserve may not match increases in sport intensity, resulting in higher risk of acute and overuse injury
Biomechanics	Increase in dynamic valgus and decrease in knee flexion angle during landing and cutting tasks	Increased risk of knee ligamentous injury during landing

Abbreviations: BMD, bone mineral density; IGF-1, insulin-like growth factor-1; PHV, peak height velocity; PWV, peak weight velocity

reproduction maturation, and increased body fat.[29] Both estrogen and testosterone interact with growth hormone to stimulate growth in stature. Insulin-like growth factor 1 (IGF-1) responds to increases in growth hormone to support skeletal development and protein synthesis.[30] Both exercise and nutrition can influence the effects of hormones responsible for pubertal growth. Young girls in a state of negative energy balance may experience a decrease in growth hormone and IGF-1, which can suppress estrogen, delay menstruation, and even weaken bone tissue.[30] Ensuring proper nutrition throughout childhood and adolescence, in addition to avoidance of overtraining, can promote healthy growth of young females.

Growth is the increase in the size of the body as a whole and of its parts.[29] Traditionally, height and weight are used to measure growth status and growth rate. Throughout childhood, young females grow an average 8.5 cm/year in height prior to adolescence, compared to 9.5 cm/year for young boys.[31] By age 10, the rate of height growth begins to accelerate in girls to >9 cm/year. This pubertal growth spurt lasts approximately 3-3.5 years until PHV is reached. Most females reach PHV by age 12, compared to age 14 for boys.[29] Following PHV, growth in height continues, but at a slower rate. The end of pubertal growth is marked by attainment of adult stature, which typically occurs around 16-17 years old for females.[31] Stature, or standing height, is the linear measurement of the distance from the floor to the vertex of the skull, commonly reported in feet and meters.[30] Somatic age, the progress toward attainment of adult body size, often varies among girls of the same chronological age. Commonly, youth female sports teams will consist of players of various somatic ages. Weight, or body

mass, is typically measured on a scale and reported as pounds or kilograms. Peak weight velocity (PWV), or period of fastest mass gain, occurs after PHV in females, ranging from a few months up to a year.[30] During the period of PWV, females add mass at a rate of 15-20 lbs/year.[29] Unlike height, however, weight can continue to increase beyond the end of pubertal growth.

Maturation is the progress towards biological maturity.[29] Throughout childhood and adolescence, young females demonstrate varying levels of maturation tempo, or the rate at which the processes of growth and maturation progress.[30] Maturity status can be monitored objectively or by self-report. Objectively, skeletal maturity can be assessed by viewing the amount of growth plate closure on radiographs of the hand or wrist.[30] Either parents or young athletes can provide a subjective report based on Tanner's criteria, a measure of sexual maturity that relies on observation of secondary sex characteristics, such as breast and genital development.[32] However, the accuracy of measuring maturity by self-report of Tanner's criteria is known to be low among youth.[33] A less invasive tool is the Pubertal Development Scale, which includes 5 questions: 3 questions related to general growth (height, body hair, skin, and acne) and 2 sex-specific questions (males: facial hair and deepening of the voice; females: breast growth and menarche).[34] For females, maturity can also be measured in relation to the timing of menarche. Menarche is defined as the first menstrual cycle, which occurs at an average age of 12-13 years.[30] When using menarche as a measure of maturity status, females are referred to as either pre-menarchal or post-menarchal. Knowledge of maturity status is important to physical therapists because maturation has the potential to influence physical performance, exercise prescription, and injury risk.[35] Because chronological age can differ markedly with respect to biological maturity, young athletes are often categorized by timing of maturation. Those biologically ahead of their respective chronological age are referred to as "early-maturing" athletes, compared to those behind their chronological age who are referred to as "late-maturing" athletes.

Development of the young female athlete refers to progress towards the adult state, which includes both biological and behavioral perspectives.[30] While the nervous, endocrine, skeletal, cardiopulmonary, and metabolic systems, among others, are undergoing significant changes during late childhood and adolescence, so too is the psychological development of the young female. During adolescence, social and emotional changes experienced may include a greater sense of personal identity, identification with a peer group, and emotional separation from parents. Cognitively, young females exert greater impulse control, increased capacity to self-regulate emotional stress, and more effective assessment of risk versus reward as compared to young male athletes.[36] Development also includes varying cultural factors and norms that will differ between young females on the same sports team. For example, female participation in sport and exercise is still discouraged in certain cultures. Cultural expectations of the attire that females wear (or are restricted from wearing) during sport may also dissuade some young girls from participating. As a result of the physical and psychological development changes that occur throughout adolescence, young females are known to demonstrate a heightened awareness of appearance and self-consciousness, in addition to a more negative body image. These psychological factors are thought to contribute to higher rates of sports participation dropout among adolescent females.[37] Within a supportive environment, participation in sports has the potential to provide a developmental "boost" during adolescence. Research has shown that sports participation can enhance short- and long-term health of female athletes by improving muscular strength, coordination, and cardiovascular fitness. Females who play sports are known to have higher levels of confidence and self-esteem, and lower rates of depression.[37] Sports participation is also associated with greater academic and career success among females.[37]

Effect of Growth and Maturation on Injury Risk

Bone health

Bone tissue development accelerates throughout childhood and adolescence to constitute most of the skeleton, which dictates approximately 98% of full adult stature. The long bones in the extremities (eg, humerus, radius, ulna, femur, tibia, fibula) are often a focus during late childhood and adolescence due to their significant rates of growth, and also because these bones are common sites of fractures and growth plate injuries.[38] Linear growth of bone is known to precede adolescent gains in BMD, leaving bones more susceptible to injury during this time. Proliferating cartilage cells between the epiphysis and diaphysis at either end of the bone constitute the active growth plates responsible for linear growth of bone. Until these zones of growth are ossified during adolescence, they are the softest and weakest sections of the skeleton. During the preadolescent years, children are often more prone to growth plate injuries compared to tendon or ligament injuries.[30] Among young females, the ossification timing of major growth plates begins earlier and is completed earlier than that in young males, resulting in an earlier cessation of growth in stature.[38] The median age of growth plate ossification in the humerus, femur, and tibia for females is between 14 and 16 years, compared to 16 and 17 years for males.[38]

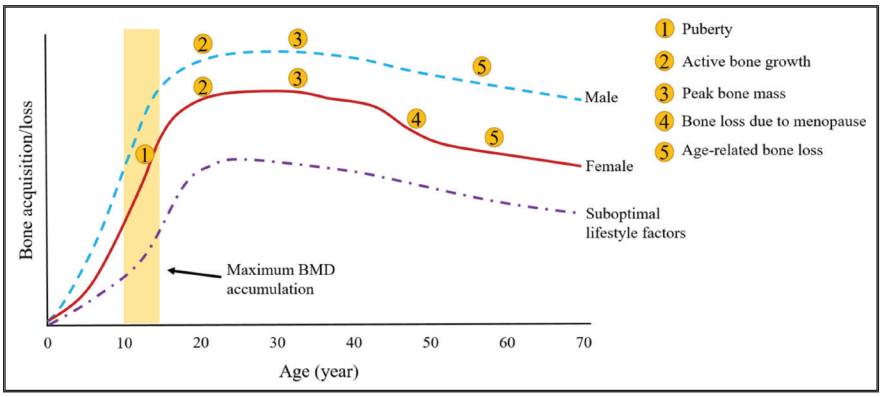
Bone mass increases similarly in young males and females prior to puberty. However, males experience a faster rate of bone mass accrual at the onset of puberty.[30] Peak bone mass (PBM) acquisition among females by the late teens or early twenties is dictated by both non-modifiable and modifiable factors. Non-modifiable factors include ethnicity, sex, and genetics. The modifiable factors that influence the achievement of PBM include physical activity, nutrition (calcium and Vitamin D intake, alcohol consumption), body mass, smoking, and co-morbidities such as obesity and diabetes.[39] Clinicians should

be aware that many of these modifiable factors are strongly influenced by socioeconomic status. It is recommended that a history intake assessment of young patients includes questions related to barriers to physical activity participation and nutrition.

The rate of bone mass acquisition is greatest during puberty, and 90% of PBM is reached by age 19.[40] More specifically, the maximum BMD accumulation takes place during a specific window surrounding the onset of menses (**Figure 2**). The 2 years before and 2 years following the onset of menses is the peak BMD accumulation period for most females.[41] Among white females, the average age of menarche is 12.3 years. African-American females and those who are overweight or obese may have an earlier average onset of menarche. For these females, the window for PBM accrual is also earlier.

Osteoporosis, a skeletal disorder characterized by compromised bone strength, typically manifests in postmenopausal women.[42] However, the disease is thought to begin with inadequate bone mass accrual during adolescence. Therefore, proper development of bone during adolescence is critical for the long-term health of young female athletes. Similar to other body tissues such as muscle or tendon, bone is a dynamic tissue that responds to changes in mechanical loads. Bone mass, structure, and strength increase with adequate stimulus throughout childhood and adolescence. Without adequate loading during these years, young females will likely lose the opportunity to achieve optimal bone mass as they transition to young adulthood, when bone mass accrual begins to slow. Lower PBM levels are known to result in a higher incidence of osteoporosis and fractures later in life. In fact, a 10% increase in PBM during development has been shown to reduce fracture risk later in life by 50% and may delay the onset of osteoporosis by up to 13 years.[39]

Figure 2. Bone Mass of Females and Males Throughout the Lifespan[a]



The purple dot-dashed line represents estimated bone mass in the presence of suboptimal lifestyle factors such as physical inactivity and poor nutrition. The yellow shaded bar indicates the time period of maximum bone mineral density accumulation for young females. Proper nutrition and adequate bone loading are recommended during these early years to prevent the onset of osteoporosis.

[a]Adapted from Zhu et al.[39]

Optimizing bone mass density

Calcium and Vitamin D are essential for PBM acquisition, as calcium is absorbed by bone and Vitamin D helps to maintain bone homeostasis.[43] Therefore, education related to adequate intake of calcium and Vitamin D should accompany any exercise prescription aimed at increasing PBM.

For optimal accrual of bone mass in the 4 years surrounding the onset of menses, a physical activity prescription should include exercises that elicit an adaptive skeletal response. More specifically, these exercises should: (1) be dynamic, not static; (2) induce high bone strain; and (3) be applied rapidly.[44] Bone tissue does not adapt well to repetitive patterns of loading, as often seen with running or cycling. Circuit training, on the other hand, can provide multi-directional, varying loads that cause bone cells to continually adapt. **Table 3** provides an example of a circuit training program designed to elicit bone tissue response. High impact activities that impart loads >4 times body weight, such as squat jumps or box jumps, can be interspersed between other exercises that target balance or strength gains. Rest breaks are important because bone cells desensitize to repetitive, non-varied loading.[38] These types of programs can easily be implemented into physical education classes, and have shown to be successful in improving bone accrual in young females.[45] Many lower extremity injury prevention programs also include similar high-intensity, bone-loading exercises (refer to the Injury Prevention Programs section of this monograph).

Some sports naturally involve greater impact loads than others, which may facilitate bone mass accrual among young females during adolescence. These include high-impact sports, such as gymnastics and volleyball, and odd-impact sports, such as soccer and basketball. Sports with rapid rates of loading also include ballet, football, power lifting, tennis, and figure skating.[44] Bone tissue has also been shown to demonstrate a local response as it adapts to stimuli. For example, the bones in the dominant arm of a young tennis player will likely contain higher bone mass as compared to the non-dominant arm.[46] The bone loading benefits of non-weight bearing exercise (eg, swimming) are thought to be similar to, or worse than, a sedentary lifestyle.[47] Simi-