Overuse Injuries and Burnout in Youth Sports: A Position Statement from the American Medical Society for Sports Medicine

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Executive Summary

BACKGROUND

- Youth sport participation offers many benefits including the development of self-esteem, peer socialization, and general fitness.
- However, an emphasis on competitive success, often driven by goals of elite-level travel team selection, collegiate scholarships, Olympic and National team membership, and even professional contracts, has seemingly become widespread.
- This has resulted in increased pressure to begin high-intensity training at young ages.
- Such an excessive focus on early intensive training and competition at young ages rather than skill development can lead to overuse injury and burnout.

PURPOSE

- To provide a systematic, evidenced-based review that will:
  - Assist clinicians in recognizing young athletes at risk for overuse injuries and burnout.
  - Delineate the risk factors and injuries that are unique to the skeletally immature young athlete.
  - Describe specific high-risk overuse injuries that present management challenges and/or can lead to long-term health consequences.
  - Summarize the risk factors and symptoms associated with burnout in young athletes.
  - Provide recommendations on overuse injury prevention.

METHODOLOGY

- Medical Subject Headings (MeSHs) and text words were searched on March 26, 2012, for MEDLINE, CINAHL, and PsychINFO.
- Nine hundred fifty-three unique articles were initially identified. Additional articles were found using cross-referencing. The process was repeated July 10, 2013, to review any new articles since the original search.
- Screening by the authors yielded a total of 208 relevant sources that were used for this paper.
- Recommendations were classified using the Strength of Recommendation Taxonomy (SORT) grading system.

DEFINITION OF OVERUSE INJURY

- Overuse injuries occur due to repetitive submaximal loading of the musculoskeletal system when rest is not adequate to allow for structural adaptation to take place.
- Injury can involve the muscle-tendon unit, bone, bursa, neurovascular structures, and the physis.
- Overuse injuries unique to young athletes include apophyseal injuries and physeal stress injuries.

EPIDEMIOLOGY

- It is estimated that 27 million US youth between 6 to 18 years of age participate in *team* sports.
- The National Council of Youth Sports survey found that 60 million children aged 6 to 18 years participate in *some*

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form of organized athletics, with 44 million participating in more than 1 sport.
- There is very little research specifically on the incidence and prevalence of overuse injuries in children and adolescents.
- Overall estimates of overuse injuries versus acute injuries range from 45.9% to 54%.
- The prevalence of overuse injury varies by the specific sport, ranging from 37% (skiing and handball) to 68% (running).
- Overuse injuries are underestimated in the literature because most epidemiologic studies define injury as requiring time loss from participation.

RISK FACTORS

- Prior injury is a strong predictor of future overuse injury.
- Overuse injuries may be more likely to occur during the adolescent growth spurt.
  - The physes, apophyses, and articular surfaces in skeletally immature athletes in a rapid phase of growth are less resistant to tensile, shear, and compressive forces than either mature bone *or* more immature prepubescent bone.
  - A decrease in age-adjusted bone mineral density that occurs before peak height velocity may also play a role.
  - Other factors that may contribute are a relative lack of lean tissue mass, an increase in joint hypermobility, and imbalances in growth and strength.
  - Physeal stress injuries appear to be more common during rapid growth and may be related to a period of vulnerability of metaphyseal perfusion.
- There is little evidence to support a causal relationship between overuse injury and anatomic malalignment or flexibility.
- A *history* of amenorrhea is a significant risk factor for stress fractures.
- Higher training volumes have consistently been shown to increase the risk of overuse injury in multiple sports.
- Other factors that may contribute to overuse injury but lack clinical data include:
  - Poor-fitting equipment, particularly when not adjusted for changes in growth.
  - Overscheduling, such as multiple competitive events in the same day or over several consecutive days. This factor may be better considered as a marker for a high ratio of workload-to-recovery time.

READINESS FOR SPORTS

- Readiness for sports is related to the match between a child's level of growth and development (motor, sensory, cognitive, social/emotional) and the tasks/demands of the competitive sport.
- Chronological age is not a good indicator on which to base sport developmental models because motor, cognitive, and social skills progress at different rates, independent of age.
- Coaches and parents may lack knowledge about normal development and signs of readiness for certain tasks, both physically and psychosocially.
  - This can result in unrealistic expectations that cause children and adolescents to feel as if they are not making progress in their sport.
  - Consequently, children may lose self-esteem and withdraw from the sport.

SPORT SPECIALIZATION

- Sport specialization may be considered as intensive, year-round training in a single sport at the exclusion of other sports.
- There is concern that early sport specialization may increase rates of overuse injury and sport burnout, but this relationship has yet to be demonstrated.
- Diversified sports training during early and middle adolescence may be more effective in developing elite-level skills in the primary sport due to skill transfer.

HIGH-RISK OVERUSE INJURIES

- "High-risk" overuse injuries are those that can result in significant loss of time from sport and/or threaten future sport participation.
- These include certain stress fractures, physeal stress injuries, osteochondritis dissecans, some apophyseal injuries, and effort thrombosis.
- High-risk stress fractures include:
  - The pars interarticularis of the spine, the tension side of the femoral neck, the patella, the anterior tibia (the "dreaded black line"), the medial malleolus, the talus, the tarsal navicular, the metaphyseal/diaphyseal junction of the fifth metatarsal (Jones fracture) and the sesamoids.
  - A high index of suspicion should be maintained for athletes complaining of pain at the sites of potential high-risk bone stress injuries including the central lumbar spine, anterior hip, groin or thigh, anterior knee, anterior leg, medial ankle, dorsal/medial midfoot, lateral foot, and plantar aspect of the great toe.
- Physeal stress injuries can occur at the proximal humerus, distal radius, distal femur, and the proximal tibia.
  - Although most physeal stress injuries resolve with rest, some may result in growth disturbance and joint deformity.
- Effort thrombosis in athletes occurs as a consequence of thoracic outlet syndrome.
  - A significant percentage of upper extremity effort thrombosis happens in adolescents as result of overuse.
  - First rib resection frequently results in a successful return to full activity.

  - All cases should undergo evaluation for an underlying coagulopathy.

BURNOUT

- Burnout is part of a spectrum of conditions that includes overreaching and overtraining.
- It has been defined to occur as a result of chronic stress that causes a young athlete to cease participation in a previously enjoyable activity.
- Sport specialization may be a factor.
  - Data suggest that athletes who had early specialized training withdrew from their sport either due to injury or burnout from the sport.
- However, not all young athletes who drop out of sports are burned out.
  - Most youth who discontinue a sport do so as a result of time conflicts and interest in other activities.
  - Some may reenter the same sport or participate in a different sport in the future.
- In children there appears to be more of a psychological component related to burnout and attrition with adult supervised activities.

PREVENTION

- Limiting weekly and yearly participation time, limits on sport-specific repetitive movements (eg, pitching limits), and scheduled rest periods are recommended. (B)
- Such modifications need to be individualized based upon the sport and the athlete's age, growth rate, readiness, and injury history. (C)
- Careful monitoring of training workload during the adolescent growth spurt is recommended, as injury risk seems to be greater during this phase. (B) This apparent increased risk may be related to a number of factors including diminished size-adjusted bone mineral density, asynchronous growth patterns, relative weakness of growth cartilage, and physeal vascular susceptibility.
- Preseason conditioning programs can reduce injury rates in young athletes. (B)
- Prepractice neuromuscular training can reduce lower extremity injuries. (B)
- Given the altered biomechanics that may occur with ill-fitting equipment, proper sizing and resizing of equipment is recommended, although data are lacking that demonstrate a link to injury. (C)
- To reduce the likelihood of burnout, an emphasis should be placed on skill development more than competition and winning. (C)

SUMMARY FINDINGS AND RECOMMENDATIONS

- Overuse injuries are underreported in the current literature because most injury definitions have focused on time loss from sport. (B)
- Preparticipation exams may identify prior injury patterns and provide an opportunity to assess sport readiness. (C)
- A history of prior injury is an established risk factor for overuse injuries that should be noted as part of each injury assessment. (A)
- Adolescent female athletes should be assessed for menstrual dysfunction as a predisposing factor to overuse injury. (B)
- Parents and coaches should be educated regarding the concept of sport readiness. (C) Variations in cognitive development, as well as motor skills, should be considered when setting goals and expectations.
- Early sport specialization may not lead to long-term success in sports and may increase risk for overuse injury and burnout. (C) With the possible exception of early entry sports such as gymnastics, figure skating, and swimming/diving, sport diversification should be encouraged at younger ages.
- When an overuse injury is diagnosed, it is essential to address the underlying cause(s). (C) The athlete, parents, and coaches should be involved in reviewing all risk factors and developing a strategy to attempt to avoid recurrent injury.
- All overuse injuries are not inherently benign. (A) Clinicians should be familiar with specific high-risk injuries, including stress fractures of the femoral neck, tarsal navicular, anterior tibial cortex and physis, and effort thrombosis.

BACKGROUND AND PURPOSE

Participation in youth sports can be an enjoyable experience for children and adolescents with many potential benefits. It offers opportunities for peer socialization, the development of self-esteem and leadership qualities, and also promotes health and fitness. However, the increasing highly competitive nature of youth sports has fueled trends of extensive training, sport specialization, and participation in large numbers of competitive events at young ages. Consequently, overuse injuries and burnout have become common.

This report will review what is currently known about the epidemiology and risk factors associated with overuse injuries and burnout in young athletes. It will highlight specific overuse injuries that may pose management challenges or lead to long-term consequences. Recommendations for prevention will also be presented.

INTRODUCTION

The number of participants in youth sports is difficult to determine. The National Federation of State High School Associations reported that 7 713 577 student athletes (4 490 854 male, 3 222 723 female) participated in 2012–2013.[1] However, this represents only a fraction of all participants at any level. Estimates for younger athletes and/or those in nonscholastic sports may best be projected from data obtained by national sport organizations. One recent survey found that approximately 27 million children and adolescents between the age of 6 and 17 years participate regularly in team sports in the United States.[2] Among specific youth sport organizations, an estimated 2.3 million children played Little League baseball, over 600 000 participate in the America Youth Soccer Organization and 365 000 play softball.[3,4] The 2008 National Council of Youth Sports survey found that approximately 60 million children aged 6 to 18 years participate in some form of organized athletics.[5] Of these, approximately 44 million participated in more than 1 sport.[5] In addition, although there is a paucity of data describing the extent of youth sport participation, it is clear that large numbers of children do not limit their sports to a given "season" and are involved throughout the calendar year in organized athletics. An emphasis on competitive success has become widespread, resulting in increased pressure to begin high-intensity training at young ages. This may be driven by parental goals of having their child selected for high-level travel teams, collegiate scholarships, and even professional contracts. Alternatively, the initiative may originate with the child or be fostered by coaches or peers. In pursuit of athletic success, children and their parents may enlist the services of a personal sport coach and/or fitness instructor, and also register for camps and showcase events. Some parents or coaches may encourage a child to concentrate on a single sport in an attempt to improve his or her chances of elite team selection, and therefore exposure to the college recruiting process. Children may also play on more than 1 team or participate in more than 1 sport at a given time. It is also important to recognize that children's sports are a big business.[6] Coaches, personal trainers, club team organizations, sporting goods manufactures, tournament directors, and others have a financial stake in youth sports participation.

Given this trend toward early and multifaceted training, frequent competition, and single sport specialization, it is no surprise that overuse injuries and burnout are common. This paper will describe several issues related to the development of overuse injury and burnout. Particular attention will be placed on the unique factors surrounding growth and development that deserve special consideration in young athletes. By understanding these issues, clinicians will better be able to treat these injuries, educate parents, athletes and coaches, and provide recommendations for injury prevention.

METHODOLOGY

Data Sources

Three electronic databases were searched on March 26, 2012, to identify potentially relevant articles: MEDLINE, CINAHL, and PsychINFO. A combination of Medical Subject Headings (MeSHs) and text words were used in this search (Table 1). A total of 953 unique articles were identified. Additional articles and related information were found using cross-referencing and the authors' personal libraries. The articles were screened by title and by abstract. Those felt to be relevant to this document were reviewed in full by the authors. The process was repeated July 10, 2013, to review any new articles since the initial search was performed. A total of 208 unique references were ultimately chosen for this paper.

TABLE 1. Search Methodology

Search Terms	PubMed Results	CINAHL Results	PsycINFO Results
Concepts around sports/athletics ["Athletes"(Mesh) OR "Sports"(Mesh) OR sport*(text word) OR athlete *(text word)]	130 431	49 948	15 207
Concepts around injuries/fatigue/burnout ["Cumulative Trauma Disorders"(Mesh) OR "injuries" (Subheading) OR trauma (text word) OR injur* (text word) OR adverse effect* (text word) OR adverse event* (text word) OR "adverse effects" (Subheading) OR "Athletic Injuries" (Mesh) OR "Burnout, Professional" (Mesh) OR "burnout" (text word) OR "burn out" (text word) OR "Fatigue" (Mesh) OR fatigue (text word)]	2 369 005	598 978	126 326
Concepts around overuse/cumulative trauma [overus* (text word) OR cumulative (text word) or "over time" (text word)]	160 436	25 300	38 716
Limits to children and human studies [child (MeSH) OR adolescent (MeSH) OR youth* (text word) OR child* (text word) OR adolescen* (text word)] NOT [animals (mh) NOT humans (mh)]	2 469 004	437 135	could not be written as single statement; see search strategy below†
Combined UNIQUE CITATIONS from search strategy results by database	**800** (803 total, but 3 duplicate citations within PubMed)	**148** (267 total citations, 119 overlapped with PubMed results)	**5** (6 total citations, 1 overlapped with PubMed results)

PubMed Strategy: ["Athletes" (Mesh) OR "Sports" (Mesh) OR sport*(text word) OR athletic*(text word)] AND ["Cumulative Trauma Disorders" (Mesh) OR "injuries" (Subheading) OR trauma (text word) OR injur*(text word) OR adverse effect*(text word) OR adverse event*(text word) OR " adverse effects" (Subheading) OR "Athletic Injuries" (Mesh) OR "Burnout, Professional" (Mesh) OR "burnout" (text word) OR "burn out" (text word) OR "Fatigue" (Mesh) OR fatigue (text word)] AND [overus*(text word) OR cumulative (text word) or "over time" (text word)] AND [child (MeSH) OR adolescent (MeSH) OR youth*(text word) OR child*(text word) OR adolescen*(text word)] NOT [animals (mh) NOT humans (mh)].

CINAHL Strategy: {[(MH "Athletes+") OR (MH "Sports+")] OR TI (sport* OR athlet*) OR AB (sport* OR athlet*)} AND {[(MH "Cumulative Trauma Disorders+") OR (MH "Athletic Injuries+") OR (MH "Overtraining Syndrome") OR (MH "Burnout, Professional") OR (MH "Fatigue+")] OR [TI (trauma OR injur* OR "adverse effect*" OR "adverse event*" OR burnout OR "burn out" OR fatigue) OR AB (trauma OR injur* OR "adverse effect*" OR "adverse event*" OR burnout OR "burn out" OR fatigue)} AND [TI (overus* OR cumulative or "over time") OR AB (overus* OR cumulative or "over time")] AND {[(MH "Child") OR (MH "Adolescence") OR TI (child* OR adolescen* OR youth*) OR AB (child* OR adolescen* OR youth*)] NOT (MH "animals" NOT MH "humans")}.

PsycINFO Strategy: †as there is no way to combine age limits and keyword searches for age in PsycINFO, 2 separate searches were conducted to get both variations.

Search 1: [DE = ("athletes" or "sports") and KW = (athlet* or sport*)] and [DE = ("fatigue" or "injuries" or "occupational stress" or "trauma") OR KW = (trauma OR injur* OR "adverse effect*" OR "adverse event*" OR burnout OR "burn out" OR fatigue)] and [KW = (overus* OR cumulative or "over time")] and [KW = (youth* OR child* OR adolescen*)].

Search 2: [DE = ("athletes" or "sports") and KW = (athlet* or sport*)] and [DE = ("fatigue" or "injuries" or "occupational stress" or "trauma") OR KW = (trauma OR injur* OR "adverse effect*" OR "adverse event*" OR burnout OR "burn out" OR fatigue)] and [KW = (overus*OR cumulative or "over time")]; Limited to Age is Preschool Age (2–5 y) or School Age (6–12 y) or Adolescence (13–17 y).

Definition of Overuse Injury

Although there is no clear consensus on the definition of overuse injury, it is generally recognized that overuse injuries occur due to repetitive submaximal loading of the musculoskeletal system when rest is not adequate to allow for structural adaptation to take place.[7–10] Such injury may involve the muscle-tendon unit, bone, articular cartilage, physis, bursa, and/or neurovascular structures. During sport participation, repetitive loading to these structures results in microtrauma. When recovery between loading exposures is sufficient, tissue adaptation occurs to accommodate the imposed stress. However, excessive stress and/or an inadequate recovery period can overwhelm the ability of the tissue to remodel, resulting in a weakened, damaged structure. This imbalance between training loads and recovery is a key factor, perhaps even more so in young athletes with an immature musculoskeletal system.

Because of ongoing growth and development, the types of overuse injuries that occur in young athletes differ compared to adults.[11,12] Specifically, growth-related conditions such as apophysitis and physeal stress injury are unique to young athletes.[13–15]

Apophyseal injuries typically occur in early adolescence. The most common sites involve the tibia tubercle of the knee (Osgood-Schlatter disease), the calcaneal apophyisis of the heel (Sever's disease), and the medial epicondylar apophysis of the elbow (often referred to as Little Leaguer's Elbow). Anterior knee pain is one of the most frequent complaints in the young athlete.[16] In early adolescence this is usually due to Osgood-Schlatter disease, while in later adolescence the tibial tubercle apophysis matures, and patellofemoral pain syndrome (PFPS) becomes the more common cause of knee pain.

Overuse injuries of the physis (eg, proximal humerus in throwers, distal radius in gymnasts) occur in early to mid-adolescence.[14,17–19] As skeletal maturity is achieved, overuse injuries to bone begin to follow adult injury patterns (eg, stress reactions and stress fractures).

EPIDEMIOLOGY OF OVERUSE INJURIES

Overall, there is very little research specifically on the incidence and prevalence of overuse injuries in children and adolescents.[20–24] Furthermore, studies of sports injuries in youth are limited by several issues including injury reporting methodology, injury classification, and standardization of outcomes. In particular, injury definitions that require time loss from sport underestimate the burden of overuse injuries.[9,25]

A recent study of 100 US high schools reported that the overall injury rate (acute and overuse) in 20 high school sports was 1.71/1000 athlete exposures (AEs) during the 2010–2011 school year.[23] This database estimates 3.7 million injuries occurred that resulted in more than 1 day's time loss from sports. This estimate does not include injuries seen outside of the high school setting. Importantly, this study further underestimates injury rates since it does not account for injuries which did not result in time loss, as is the case in many overuse injuries.[9] Another data source, the National SAFE KIDS Campaign, estimates that more than 3.5 million children are injured annually playing sports or participating in recreational activities.[22]

Estimates of the proportion of all sports injuries that are due to overuse range from 45.9% to 54%.[7,24,26] Although evidence is sparse, there is concern that these injuries are increasing.[27–29] The frequency and type of overuse injuries in elite young athletes varies by sport and by age.[30] Sport-related training and conditioning are also factors (eg, resistance training as an adjunct to soccer training).[30] Overuse, noncontact injuries in American football are 2.6 times more likely to occur at the college level than high school.[31] In a recent 3-year study of 16 sports at 1 university, 29.3% of injuries were considered overuse injuries.[9] Baxter-Jones et al studied 453 elite young athletes in 4 sports (231 boys, 22 girls; 8–16 years of age) and found that the prevalence of overuse injuries varied by sport: 63% for swimmers, 33% for gymnasts and tennis players, and 15% for soccer players.[30] Other studies report the prevalence of overuse injury among different youth sports to range from 37% (skiing and handball) to 68% (running).[32–34]

TABLE 2. Categorization of Risk Factors for Overuse Injury

Intrinsic Risk Factors
Growth-Related Factors
Susceptibility of growth cartilage to repetitive stress
Adolescent growth spurt
Previous injury
Previous level of conditioning
Anatomic factors
Menstrual dysfunction
Psychological and developmental factors—athlete specific
Extrinsic Risk Factors
Training workload (rate, intensity, and progression)
Training and competition schedules
Equipment/footwear
Environment
Sport technique
Psychological factors—adult and peer influences

(Adapted from DiFiori JP. Evaluation of overuse injuries in children and adolescents. Curr Sports Rep. 2010;9:372–378.).

RISK FACTORS FOR OVERUSE INJURIES

A variety of factors have been proposed to contribute to overuse injuries. They are often grouped into either intrinsic or extrinsic factors (Table 2). Intrinsic factors are defined as individual biological characteristics and psychosocial traits. Extrinsic factors refer to external forces related to the sport type, the biomechanics of the activity, and the sporting environment.[35] Commonly cited intrinsic factors include variations in growth and development, anatomic alignment, muscle-tendon imbalance, flexibility, conditioning, biomechanics, and a history of prior injury. Extrinsic factors include workload, sport technique, training environment, and equipment. The contribution of an intrinsic or an extrinsic factor to injury risk is extremely variable depending on the individual athlete, the sport environment, and the interaction that occurs during participation.[35–37]

Furthermore, it is important to recognize that many overuse injuries result from a complex interaction of multiple risk factors in specific settings coupled with an inciting event. Understanding this concept is necessary for the comprehensive evaluation and treatment of athletes with overuse injuries.[38,39]

It is also relevant to note that some risk factors are modifiable (eg, strength, neuromuscular function), whereas others are not (eg, age, gender).[38] Finally, in young athletes, characteristics of the developing musculoskeletal system are especially important to consider.

Although little data exist that identifies a causal relationship between proposed risk factors and overuse injury, recognizing these potential contributors to injury is important in limiting recurrent injury and in developing injury prevention strategies.[15,37,40]

Intrinsic Risk Factors

Prior Injury

Previous injury is the strongest predictor of future injuries.[41–50] Repeated overuse injury may occur as a result of inadequate rehabilitation of the index injury and/or a failure to recognize and correct the factors that contributed to the original injury.

Growth and Development

Children undergo growth and development at an individual rate. Biologic growth and maturation are primarily genetically regulated; development is more culturally mediated.[36,51] For example, the development of child's play paradigms can vary depending on the cultural exposure to solitary play, parallel play, associate play, and cooperative play situations.[52] Physical growth and cognitive development both influence successful participation in sports.

Overall body mass and height increase in the preadolescent and adolescent years.[53] Girls tend to reach their peak height and body mass at approximately age 15, whereas boys may experience increases beyond age 18. Maturation is a complex process that encompasses skeletal, somatic, and sexual maturation. Each component of maturation occurs at an independent, sometimes asynchronous, rate in an individual. Although wide variations in the maturation rates have been suggested to increase injury risk, data demonstrating a definitive link between discordant maturation and injury are lacking.[54,55]

Overuse injuries may be more common during the adolescent growth spurt. Laboratory studies demonstrate that the growth cartilage present at the physes, apophyses, and articular surfaces in skeletally immature athletes in a rapid phase of growth are less resistant to tensile, shear, and compressive forces than either mature bone or more immature prepubescent bone.[56–58] Acute distal radius fractures peak during and just before peak height velocity.[59,60] Stress fractures, distal radial physeal stress injuries, and low back pain also appear to occur with a greater prevalence during the adolescent growth spurt.[61–63] Prospective studies are needed to further evaluate this relationship.

A decrease in age-adjusted bone mineral density that occurs before peak height velocity may also play a role.[64] A relationship to acute traumatic fractures has been demonstrated, but its role in overuse injury has not yet been determined. In addition, dissociation is seen between bone matrix formation and the occurrence of bone mineralization during the growth spurt resulting in relatively diminished bone strength.[64,65]

Other factors that may contribute are a relative lack of lean tissue mass, an increase in joint hypermobility, and imbalances in growth and strength.[66–69] Longitudinal growth of extremities results in changes in length, mass, and stress forces on bone-tendon junctions, muscle-tendon junctions, growth cartilage, and ligaments that frequently occur asynchronously.[69] These imbalances in growth and strength, coupled with repetitive loading, appear related to increased injury risk, although the exact relationship is not clearly delineated and is likely multifactorial.

Overuse injuries of the physis may be due to diminished perfusion related to excessive mechanical loading. Magnetic resonance imaging (MRI) of physeal stress injuries of the distal radius in young gymnasts shows an appearance similar to experimentally induced injuries in which metaphyseal artery perfusion has been disrupted.[55,70–72] This injury is significantly more likely to occur in gymnasts who are within the expected age range of the adolescent growth spurt.[19,61]

Anatomic Alignment

Alignment abnormalities such as patellofemoral malalignment, pes planus, pes cavus, elbow hyperextension, and excessive lumbar lordosis are some of the more commonly cited risk factors for overuse injuries.[21,73–75] Joint hypermobility has also been associated with injury in some studies.[76,77]

Accurate assessment of these factors, including measuring both static and dynamic components, is difficult to achieve in the office setting. In addition, defining a cause and effect relationship between these characteristics and injury has been elusive.[78,79] Recent studies have not established consistent predictors. Given the broad diversity of sport-specific demands placed on the body, considerably more information is needed to formulate models whereby anatomic alignment may predict injury risk.[73,80,81] Overall, the significance of osseous alignment abnormalities versus soft tissue alignment abnormalities in relation to injury is complex, poorly understood, and likely sport specific.

Alignment can be altered through use of supportive equipment. The use of custom shoe orthotics to alter alignment, particularly in runners, is controversial, yet widely used. The use of an orthotic can have both a short- and a long-term effect on lower extremity kinematics such as rearfoot eversion angles, velocity, impact peak, and loading rate, as well as knee kinematics. However, the clinical significance of this with regard to effects on injury rates remains unknown.[82] There is also the potential to increase injury risk depending on the effect of the altered kinematics on sport participation.

Flexibility

A causal relationship between flexibility and injury risk has not been documented. Early reviews proposed that inflexibility across the muscle-tendon unit develops during the adolescent growth spurt that may contribute to injury.[83]

However, several recent studies have not shown any relationship between growth and inflexibility in boys or girls.[84–86] Studies investigating the role of pre-exercise stretching on injury risk have shown mixed results.[87,88] Interventions that consider age, gender, and specific sports are needed.

Biomechanics

Limb length, body mass, and moments of inertia change rapidly during the adolescent growth spurt, and all can affect coordination and movement patterns.[53,66,69] This is likely due to the need for greater force generation for extremity movement during a time when strength and coordination are still developing. This may play a role in the increased risk for injury seen during the growth spurt.[35,36,55–63]

Structural or dynamic disturbances in extremity mechanics appear to increase eccentric loads.[69,89] These findings can then serve as the basis for targeted rehabilitation programs that emphasize improvement in sport-specific biomechanics.[89,90] In some cases, it is not clear if sport-related changes in joint range of motion play a role in overuse injury or reflect a positive biomechanical adaptation.[91,92] In overhead athletes, a decrease in dominant arm internal rotation coupled with greater strength in internal rotators is typically seen relative to the nondominant arm.[91] One laboratory study in Peewee ice hockey players performing a sprint start displayed "at risk" hip kinematics including internal hip rotation during flexion or "push-off" phase and external rotation during abduction or recovery phase, thus placing the hip in a position to potentially cause femoroacetabular impingement and/or labral stress.[93] These studies suggest sport-specific kinematic profiles deserve further investigation to determine if such factors predispose to overuse injury.

Strength and Conditioning

Benefits of youth fitness include those related to cardiovascular health, bone health, and mental health.[94–96] Among young athletes, general activity and fitness levels vary greatly. Children who have not developed some foundation of general strength, endurance, and motor skills may be at increased risk for injury, although little data exist at this time. Some potential risk factors that are modifiable include poor endurance and lack of preseason preparation.[97–101]

Menstrual Irregularity and Low Energy Availability

A history of amenorrhea, especially in sports that emphasize leanness, is a risk factor for bone stress injury. One study in collegiate female distance runners found a linear relationship between number of menses per year and risk of stress fracture, with amenorrheic runners having the highest risk.[102] Several studies have suggested that a history of amenorrhea is a significant risk factor for stress fractures.[99,101–105] The proposed mechanism correlates inadequate caloric intake with hypoestrogenemia, decreased bone density, and subsequent increased fracture risk.[106,107] The relationship between oral contraceptive use and the likelihood of stress fracture is not well understood.[108] The studies cited generally focused on young women and older adolescents. There is little data regarding menstrual irregularity, low energy availability, and overuse injury in younger adolescents. It is important that female athletes with bone stress injuries who are found to have menstrual irregularity are also screened for disordered eating and low bone mineral density (ie, the female athlete triad).[107]

Extrinsic Risk Factors

A variety of extrinsic factors such as sport technique and biomechanics, the volume and intensity of workloads, training environments, and equipment all have been theorized to affect overuse injury rates. Importantly, these are modifiable risk factors.

Workload

Higher training volumes have consistently been shown to increase the risk of overuse injury in multiple sports.[26,109–112] In a study of 2721 high school athletes, there was a linear relationship between hours of sport participation and risk of injury.[110] Specifically, training more than 16 hours per week was associated with a significantly increased risk of injury requiring medical care.[110,113,114]

The volume and intensity of training is correlated with overuse injury risk.[79,109,115–117] In youth baseball, studies have shown that among pitchers, pitch volume has the greatest association with injury rate.[118,119] Additionally, a 10-year prospective analysis of 481 youth baseball pitchers ages 9 to 14 years found a 3.5 times greater likelihood of suffering an injury resulting in time lost from sport participation in those players who pitched greater than 100 innings per year.[111] Among young gymnasts, wrist pain was significantly related to training intensity, as measured by skill level and number of hours training per week.[117] The recommended workload varies greatly depending on the sport, as well as individual characteristics, making it a challenge to define sport-specific workload thresholds that are related to increased injury rates.[15,26,117]

Scheduling

Scheduling issues have recently received more attention as possible factors that increase injury risk in youth athletes. Concern has been raised for year-round training in a single sport and simultaneous involvement in multiple teams in the same sport. Tournament scheduling, where several games are often played in a single day, extending over consecutive days, is also a potential factor.

One large cohort study showed that elite soccer players younger than age 14 sustained more acute and overuse injuries in training compared to older players.[11] The frequency was highest early in the season for the younger players, compared to older players who suffered more game-related injuries. This suggests that younger players who reach elite levels may not have achieved optimal fitness levels and/or are experiencing training volumes and intensities that may adversely affect injury risk.

Studies in a variety of sports such as baseball, tennis, cricket, running, and soccer have demonstrated that high workloads between bouts of activity are consistently associated with increased injury risk.[109,111,112,120,121] One study evaluating the relationships between seasonal patterns of athletic participation and overuse injury demonstrated a 42% increase in self-reported overuse injuries in high school athletes who participated all year versus 3 or less seasons per year.[121]

Tournament scheduling and showcases have also been a concern. Repeated same-day exercise has been shown to increase cardiovascular and thermal strain as well as perception of effort in subsequent activity bouts. Although there is little data to link these issues with overuse injury, longer rest periods between matches and games have been proposed in an effort to improve athlete safety and performance, enhance recovery, and minimize the "carryover" effects from previous competitions and environmental exposure.[28] In terms of overuse injury, scheduling may simply be a marker for a high ratio of workload-to-recovery time.

Equipment

Improper sizing and poor maintenance of equipment, as well as failure to use equipment that is appropriate for the sport may contribute to injury. Common examples of equipment concerns include grip size and string tension in racquet sports, weight and length of bats or other hand-held equipment, bike size, shoe type and fit, use of training aids such as swim paddles and weights, or other resistive training devices used during training. However, data is lacking with regard to direct relationships with overuse injuries.

READINESS FOR SPORTS

Readiness for sports can be defined in terms of the match between a child's level of growth and development (motor, sensory, cognitive, social/emotional) and the tasks/demands of the competitive sport.[122] On the one hand, if a young athlete is expected to learn too many skills that are beyond their ability, there will be little motivation to learn new skills.[123] On the other hand, mastering tasks and developing a feeling of competence may sustain a child's interest and motivate him or her to learn new skills.[124]

Unfortunately, coaches and parents often lack knowledge about normal development and signs of readiness for certain tasks, both physically and psychosocially. This can result in unrealistic expectations that cause children and adolescents to feel as if they are not making progress in their sport, especially related to their chronological peers. Consequently, children may lose self-esteem and withdraw from the sport.[125]

Physical growth and developmental readiness is important in order to learn the skills for sports. For example, a child cannot kick a ball until she or he has the strength and balance to stand on 1 leg to swing the kicking leg.[126] However, readiness to learn specific skills cannot be determined by chronological age, body size, or biologic maturation alone.[127] Readiness is assessed by determining what requisite antecedent skills will provide the basis for mastering the new activity.[127] For example, children must have good eye tracking before being able to hit a pitched ball.[128]

Cognitive development must occur before the young athlete can participate in most organized sports. In early childhood, the young athlete may not understand the need to stay in position or be able to remember instructions.[126] To enjoy a sport, the youngster needs to understand the fundamental rules and strategy of the sport. He or she must also have the cognitive ability to follow directions and interact with their fellow team members.

As with other child developmental milestones, motor skills develop at different rates among individuals.[128] Therefore, there is no chronological age that will guarantee mastery of a certain task. However, for most motor skills, the young athlete will follow a predictable and necessary sequence. For example, learning to kick a ball requires 4 stages: first pushing a ball while standing, then learning to kick a ball with some wind-up, then taking a step or 2 to kick, and finally taking several rapid steps with a small leap before the kick.[126]

It is important for parents and coaches to be mindful of what activities are appropriate for each age group.[126] For ages 2 to 5 (early childhood), children have limited fundamental skills and poor balance. Appropriate activities for this age group include running, swimming, tumbling, throwing, and catching. For the child 6 to 9 (middle childhood), posture and balance become more automatic, reaction times are improved, and transitional skills are emerging. Activities can include running, swimming, skiing, entry-level soccer, baseball, tennis, gymnastics, and martial arts. For the child 10 to 12 years of age, most can master complex motor skills but may have a temporary decline in balance skills during the pubertal growth spurt.[129] For this age group, entry level for complex skill sports is appropriate in most cases. This includes football, basketball, hockey, and volleyball.

Thus, there is no simple way to determine if a child is ready for a particular sport. Four factors should be considered: sport-related skills, knowledge about the sport, motivation, and socialization.[130] Chronological age is not a good indicator on which to base developmental models.[131] Informal participation with family and friends can be a helpful gauge.[130] Fortunately, when given the chance, children will naturally select and modify activities so that they can participate successfully and have fun.[126]

SPORT SPECIALIZATION

Sport specialization may be considered as intensive, year-round training in a single sport at the exclusion of other sports.[132] Although the degree of specialization may occur along a spectrum, there is no consensus about what type of specialized training is most appropriate to develop elite-level skills. In addition, there is debate about whether early specialized training and intensive training volumes are necessary to achieve high skill levels in sports or if beginning more specialized and intensive training during late adolescence is more advantageous. Furthermore, there is growing concern regarding the potential negative effects of early sports specialization, including injury and sport burnout.

Although there are many examples of early specialized sports training, it appears that such training may be necessary in those technical sports that require elite-level competition prior to full maturation such as gymnastics or rhythm gymnastics, figure skating, and swimming/diving.[133,134] This type of early specialized training typically occurs before the age of 12, and frequently as young as 5 or 6 years of age.

The cumulative amount of training necessary to achieve elite-level status may be far less than the 10 000 hours that some have proposed.[133–135] More commonly, specialized, intense training occurs at later ages in many other sports and seems to be important with sports that require more physical skills or maximal aerobic capacity.[135] Diversified sports training during early and middle adolescence may be a more effective strategy in ultimately developing elite-level skills in the primary sport due to a positive transfer of skills.[136] Consideration should be given to delaying intensive, specialized training until late adolescence, rather than a specific age, to optimize skill development in most sports.

There are both theoretical and measurable risks associated with intense, specialized training. Injury rates in high school athletes have a direct relationship to exposure by h/wk.[110] Other studies have found increased exposure to be an additional risk for injury, such as in youth baseball pitchers who pitch >8 mo/y who are more likely to have shoulder or elbow surgery.[109] Meanwhile, as mentioned earlier, among youth pitchers, those who pitched more than 100 innings/year were 3.5 times more likely to be injured.[111] Other risks related to intensive training include increased risk for injury with increased skill level and increased competition.[112,117,137]

The relationship between injury and sports specialization has not been clearly demonstrated. In 1 study evaluating 519 junior competitive tennis players, those players who reported competing only in tennis were 1.5 times more likely to have reported an injury.[138] However, this study did not account for training intensity (eg, weekly training hours). Early data from a clinical study comparing young athletes with sports-related injuries to healthy, uninjured athletes presenting for sports physicals suggests that more specialized athletes were more likely to be injured.[139]

Future research in this area should evaluate the relationship of overuse injury and high-risk injury to specialized training while controlling for training intensity and year-round training. Additionally, it would be worthwhile to evaluate multi-sport athletes longitudinally compared to specialized athletes at various ages and stages of development to compare the effects of sport diversification with specialization.

HIGH-RISK OVERUSE INJURIES

Some overuse injuries may be described as "high risk" in that if they are unrecognized or inappropriately treated, they can result in significant loss of time from sport and/or threaten future sport participation. High-risk overuse injuries include certain stress fractures, physeal stress injuries, osteochondritis dissecans, some apophyseal injuries, and effort thrombosis (Table 3).

Stress Fractures

Bone stress reactions and stress fractures can occur in children as they do in adults, and risk factors are similar for both age groups.[62] Most heal uneventfully if treated appropriately with rest, rehabilitation, and graded return to activity. However, certain stress reactions or fractures do not heal readily, and are thus deemed high risk. If these high-risk injuries are not identified and treated properly, the injury may go on to nonunion, result in chronic pain, and/or lead to the development of degenerative joint disease. For example, nonunion of a stress fracture of the tarsal navicular can lead to degenerative joint disease of both the talonavicular and naviculocuneiform joints.[140]

High-risk stress reactions and stress fractures include those to the pars interarticularis of the spine, the tension side of the femoral neck, the patella, the anterior tibia (the "dreaded black line"), the medial malleolus, the talus, the tarsal navicular, the metaphyseal/diaphyseal junction of the fifth metatarsal (a Jones fracture), and the sesamoids[62] (Table 3). The incidence and prevalence of these injuries in children is not well described. Overall, delayed union and nonunion have been reported to occur in up to 10% of athletic stress fractures.[141] Delayed union and nonunion were most often seen in the hallux sesamoids, mid-tibial shaft, metaphyseal/diaphyseal junction of fifth metatarsal, tarsal navicular, and olecranon.[141]

Spine (Pars Interarticularis)

Stress fractures of the pars interarticularis (spondylolysis) are a relatively common cause of back pain in active children. They are most frequent at the fourth and fifth lumbar vertebrae.[142] Among young athletes evaluated for back pain, 48.5% of young athletes were found to have occult spondylolysis.[143,144] Progression to nonunion ranges from 14% to 70%, with those who are untreated or undergo delayed treatment having the highest rates of nonunion. In a retrospective analysis of 57 youth soccer players diagnosed with lumbar spondylolysis, those who took at least 3 months off from the sport with or without bracing had the most optimal results.[145]

TABLE 3. High-Risk versus Low-Risk Overuse Injuries

Location	High Risk	Low Risk
Hip/Pelvis	Femoral neck (tension-sided)	Femoral shaft stress fracture
Back (lumbar spine)	Pars interarticularis stress fracture	Congenital spondylolysis, pedicle stress fracture
Leg	Anterior cortical tibial stress fracture	Medial tibial stress fracture, fibular shaft stress fracture
Ankle	Medial malleollar stress fracture, talar dome osteochondral defect, talar neck stress fracture	Distal fibular stress fracture
Foot	Tarsal navicular stress fracture, fifth metatarsal proximal diaphyseal stress fracture, sesamoid stress fracture	Second, third, fourth metatarsal stress fractures, cuboid
Knee	Patellar stress fracture, osteochondritis dissecans of femoral condyle or patella	Tibial tubercle and inferior patellar pole apophysitis
Shoulder/arm	Effort thrombosis	Proximal humeral physeal stress fracture
Elbow	Osteochondral dissecans capitellum, apophyseal nonunion of medial epicondyle	Medial epicondyle apophysitis
Wrist	Distal radial physeal stress injury	

In another series evaluating outcomes of pars stress fractures in young athletes, the average time needed to return sport was 5.4 months.[146] The decision regarding rigid anti-lordotic bracing remains controversial, though most would agree that a period of rest, with or without bracing until pain free, is necessary.[147] Progression to spondylolisthesis of >20% occurs in only about 4% of cases over 7 years of follow-up.[148] In a 45-year natural history study of pediatric spondylolysis, there was no risk for spondylolisthesis if the injury was unilateral.[149] Surgical pars repair may be indicated for painful spondylolysis with nonunion after 6 months of nonoperative treatment and at least 9 to 12 months of symptoms.[150] Surgical fusion may be indicated for spondylolisthesis >50%, and may be a relative indication for those with persistent radicular or neurologic symptoms in the setting of spondylolysis.[150]

Femoral Neck

Stress fractures of the femoral neck are not common in children and adolescents but have been reported.[151,152] If not recognized early and treated, complete fracture may occur, with significant long-term implications.[152] A high index of suspicion should be maintained with any young athlete who presents with anterior hip or groin pain. If x-rays are negative, an MRI should be obtained for diagnosis. Although the majority of these are compression-sided fractures, there are case reports of tension-sided fractures in youth.[153] Tension-sided fractures should be referred to an orthopedic specialist and treated with strict nonweight-bearing and/or open reduction with internal fixation just as in adults because of the risk of nonunion, progression to a pathologic fracture, and development of avascular necrosis.[152]

Patella

Case reports of patellar stress fractures in children exist, but the true incidence is unknown.[154,155] Patellar stress fractures should be treated with a 4- to 6-week period of immobilization in a long leg cast, but may heal faster than adults. Any displaced fracture or fracture with nonunion should be referred for surgical fixation.

Anterior Tibia

Anterior cortical tibial stress fractures are tension-sided injuries that have a high risk of nonunion. Radiographs may display a defect of the anterior cortex, often referred to as the "dreaded black line." If radiographs are negative, MRI or computed tomography (CT) with thin cuts may be helpful in making the diagnosis.[156] In 1 case series, anterior tibial stress fractures were reported in 7 males and 4 females (mean age of 17 years).[157] All patients had failed nonoperative treatment for a minimum of 4 months and had experienced symptoms for a mean of 12 months. All were treated with reamed intramedullary nailing. Clinical and radiological union occurred at 3 months. The mean duration for return to sports after surgery was 4 months.[157]

Ankle (Medial Malleolus)

Stress fractures of the medial malleolus are rare. In 1 case of a 15-year-old elite gymnast with open physes, the patient was treated initially with rest and then gradually returned to full activity.[158] Two months later, however, she developed a complete fracture of the medial malleolus. This was treated surgically by open reduction and internal fixation with a cancellous screw with subsequent return to full activity.

Foot

In a retrospective review of 3 decades of x-rays from a single pediatric orthopedic clinic, 507 children with tarsal stress fractures were identified. Of the tarsal stress fractures identified, the following specific bones were involved: calcaneus (244), cuboid (188), talus (121), navicular (24), and cuneiforms (23). Many occurred during resumption of weight bearing after cast immobilization for another injury.[159]

The incidence of tarsal navicular fractures in the pediatric athletes is unknown. There is a case report of a 13-year-old athlete in the literature.[160] The highest incidence appears to involve track and field followed by football or soccer.[160] These fractures often have a delay in diagnosis as symptoms are vague, and the fracture plane may be missed on radiographs. Thus, advanced imaging with CT or MRI is often needed.

Stress fracture of the sesamoids of the great toe was reported in 5 female athletes (mean age 16.8 years; range, 13–22 years).[161] When this injury is suspected, bone scan and CT scan are suggested as more reliable in confirming the diagnosis than other imaging methods. After failure of conservative treatment measures, surgical excision of the proximal fragment was successful in all patients. All patients regained full sports activity within 6 months (range, 2.5–6 months).

Although stress fractures of the talus and fifth metatarsal metaphyseal/diaphyseal junction are well described in adults as problematic injuries, there is no specific data regarding these injuries in children.

Clinical Clues to High-Risk Stress Fractures

A high index of suspicion should be maintained for athletes complaining of pain at the sites of potential high-risk bone stress injuries. These sites include the lower lumbar spine, anterior hip, groin or thigh, anterior knee, anterior leg, medial ankle, dorsal/medial midfoot, lateral foot, and plantar aspect of the great toe (Table 4). Because the spine cannot be adequately palpated on exam, history alone is cause for further imaging. For femoral neck stress fractures, palpation is not helpful. Pain may be reproduced with passive hip internal rotation, but the history may be the only clue that prompts imaging. For the other sites, palpable tenderness over the bone warrants definitive imaging.

Imaging of Stress Reactions and Stress Fractures

Imaging for stress reactions/fractures should begin with x-rays. However, bone stress injuries may not be visible on plain radiographs for several weeks following the onset of pain, and some may never become apparent on plain radiographs. Magnetic resonance imaging is the study of choice for early stress fracture diagnosis in most situations. A SPECT bone scan is frequently used for diagnosing spondylolysis, though MRI with STIR sequences is being used increasingly in some institutions. Early stress injuries and incomplete fractures to the pars interarticularis and pedicle in the lumbar spine may be missed on traditional MRI, and may need to be sequenced to enhance the ability to diagnose an early spondylolysis.[162] The use of triple phase bone scans has fallen out of favor because of the radiation exposure and lack of specificity; however, they can be helpful in diagnosing rib stress injuries, or when the source of the pain cannot be localized on exam.

Treatment of high-risk stress reactions and stress fractures depends on the specific site of the injury (Table 4). For fractures that fail to heal and cause persistent symptoms, open reduction with internal fixation may be required. Surgical treatment may also be considered as initial treatment for stress fractures of the tension side of the femoral neck, anterior tibia, tarsal navicular, and at the diaphyseal/metaphyseal junction of the fifth metatarsal.

Prevention of Stress Fractures

There are no studies specifically on prevention of stress fractures in the pediatric and adolescent population. However, since the risks factors are generally the same as in adults, it is reasonable to employ the same prevention strategies including setting limits on impact activities, optimizing Vitamin D and calcium intake, screening for the female athlete triad, and considering the use of shoe orthotics. Early recognition is the key to optimal treatment.

Physeal Stress Injury

Physeal stress injuries related to participation in sports are known to occur, although injury incidence data are limited. Although most physeal stress injuries appear to resolve with rest, there is evidence that some may cause growth disturbance and joint deformity.[13]

Stress injury to the physis has been documented to occur at the proximal humerus, distal radius, distal femur, and the proximal tibia.[17,72,163–166] Although symptoms may be prolonged, stress injury to the proximal humeral physis does not appear to have long-term consequences.[17] Consequences of early closure of the distal femoral and proximal tibia physes can be significant as they account for 60% and 70% of the growth of those respective bones.[167] Stress injury to theses physes may result in leg length discrepancy or angular or rotational malalignment of the affected leg.[165]

Perhaps the most studied physeal stress injury involves the distal radius in young gymnasts.[19] A potential consequence of repetitive stress injury to the distal radial physis in gymnasts is premature physeal closure.[168] If this occurs prior to closure of the distal ulnar physis, positive ulnar variance may ensue, which can lead to impingement of the triangular fibrocartilage complex, degenerative joint disease, and chronic ulnar-sided wrist pain. In a systematic review of the literature, radiographic abnormalities consistent with distal radius physeal stress reaction were described in 10% to 85% of gymnasts. Two studies indicated "abnormal" positive ulnar radial length discrepancy in 8% to 20%. Four studies showed significant correlations between training intensity and ulnar radial length discrepancy, suggesting a dose-response relation. Radiographic evidence of distal radial physeal arrest involving skeletally immature female gymnasts was reported in 4 studies. The results support the plausibility that stress-related distal radius physeal arrest may occur and lead to the subsequent development of positive ulnar variance, but are not conclusive.[13,19]

Physeal injury of the knee has been described in both the distal femur and proximal tibia of young athletes with knee pain.[163–166] This abnormality may be visible on x-ray or T2-weighted MRI. In a retrospective review of the largest case series of 6 athletes, 5 were treated with 3 to 5 weeks rest and immobilization and had resolution of their pain and physeal widening at 1 to 3 months. One athlete continued intense training despite medical advice and developed bilateral genu varum deformities over the following 2 years.[165] Further, boys who play load-bearing sports (track and field, basketball, volleyball, field hockey, tennis, badminton, and squash) show a significantly increased amount of genu varum from 13 to 15 years or older compared with sedentary boys.[169] Growth plate widening has also been described in the distal tibia and fibula in young athletes.[170]

TABLE 4. Location of Pain for High-Risk Stress Fractures

Pain Site	Corresponding Stress Fracture
Lower lumbar spine	Pars interarticularis
Anterior hip/groin/thigh	Femoral neck
Anterior knee	Patella
Anterior lower leg	Anterior tibia
Medial ankle	Medial maleolus
Dorsal/medial foot	Tarsal navicular
Lateral foot	Fifth metatarsal (Jones)
Plantar great toe	Sesamoids

Osteochondritis Dissecans

This injury to the subchondral bone and articular cartilage of joints may develop in young athletes from overuse or acute trauma. Recent data suggests that osteochondritis dissecans (OCD) lesions occur due to injury affecting endochondral ossification from the secondary physis.[171] The most common OCD sites are the femoral condyles, capitellum, and the talar dome. Osteochondritis dissecans typically occurs in the adolescent age group. Joint pain, swelling, limited motion, and mechanical symptoms are common. Radiographs may confirm the diagnosis. Magnetic resonance imaging may be needed for diagnosis if x-rays are not confirmatory. Magnetic resonance imaging is recommended for staging of OCD lesions with unstable lesions defined as articular fluid tracking behind the lesion.[172] Stable lesions are initially treated nonoperatively and are more likely to heal if the physes are still open. Surgery is indicated for unstable lesions and for stable lesions that do not respond to nonoperative management.[173]

Recalcitrant or Complicated Apophyseal Injuries

Most cases of apophysitis resolve when the physis closes. However, a small number of these apophyses never fuse and may result in an ossicle that causes persistent pain. This can occur at the tibial tubercle, medial epicondyle, ischial tuberosity, olecranon apophysis, and the base of the fifth metatarsal. The incidence of apophyseal nonunion is unknown. In addition to nonunion, persistent pain may occur as a result of hypertrophy that results in a bony prominence that may be painful with trauma or overuse. This has been observed at the tibial tubercle, anterior inferior iliac spine, and ischial tuberosity. If the pain continues after skeletal maturity, ossicle resection, and/or tubercleplasty have been shown to be beneficial.[174,175]

Effort Thrombosis

Effort thrombosis of the upper extremity typically occurs in athletes as a consequence of thoracic outlet syndrome (TOS). This venous form of TOS affecting the subclavian vein is sometimes referred to as Paget-Schroetter syndrome. Common presenting symptoms are unilateral arm swelling and discoloration. Case reports of effort thrombosis in adolescent athletes have been published.[176,177] In 1 series of 32 cases of effort thrombosis in athletes (age range 16–26 years), 31% occurred in adolescents.[178] The most extensive report of venous TOS in adolescents was recently published.[179] This study described 17 adolescents with subclavian vein thrombosis (age range 10–18 years). Ten of these 17 cases were associated with athletic activities or overuse in other activities. All patients in this study underwent first rib resection and postoperative venography, with 13 requiring a period of anticoagulation post procedure. In both of these recent studies, patients with effort thrombosis treated with first rib resection regained full use of the affected extremity.[178,179] The median time for return to full activity was 3.5 months.[178] Because the contralateral extremity may be affected, diagnostic testing should be considered, even if that extremity is asymptomatic. In addition, all patients with effort thrombosis should undergo evaluation for an underlying coagulopathy.[179]

BURNOUT

Burnout may be thought of as part of a spectrum of conditions that includes overreaching and overtraining. Overreaching may be functional or nonfunctional. Nonfunctional overreaching is defined as intense training that leads to a longer period of decreased performance than functional overreaching, but both result in full recovery after a rest period. Nonfunctional overreaching is further accompanied by increased psychological and/or neuroendocrinological symptoms.[180] Overtraining syndrome is defined as extreme nonfunctional overreaching, with a longer performance decrement (>2 months), more severe symptomatology, and maladaptive physiology, and an additional stressor not explained by other disease.[180] It has also been defined as a "series of psychological, physiologic, and hormonal changes that result in decreased sports performance."[181,182]

Burnout has been defined by R.E. Smith as a "response to chronic stress" in which a young athlete ceases to participate in a previously enjoyable activity.[183] The young athlete withdraws from the sport because they perceive it is not possible to meet the physical and psychological demands of the sport.[184] Four stages of burnout were described by Smith in 1986: (1) the young athlete is placed in a situation that involves varying demands; (2) the demands are perceived as excessive; (3) the young athlete experiences varying physiological responses; and (4) varying burnout consequences develop (ie, withdrawal).[183] In addition, Coakley states that the development of unidimensional self-conceptualization and lack of control leads to stress and ultimately burnout.[184] The more fun and satisfaction the child perceives, the less anxiety they experience.[184] Low self-esteem, low personal performance expectation, worrying more about failure and adult expectations, and increased parental pressure to participate are associated with increased anxiety.[184] Excessive athletic stress can lead to loss of sleep and appetite, decreased fun and satisfaction, physical injury, lower performance, and subsequent withdrawal from the sport.[184] Although stress in appropriate levels may be beneficial by learning stress coping skills to use later in life, this has not been studied.[184]

Attrition occurs when athletes drop out of their sport either permanently or temporarily. However, it is important to recognize that not all young athletes who drop out are burned out. In fact, most young athletes discontinue a sport due to time conflicts and interest in other activities, not because of excessive stress or burnout.[184] Studies have shown that "youth sport attrition is a complex phenomenon influenced by a variety of personal and situational variables."[122] The most common variable is time conflicts with other activities. Others include interest in other activities, lack of playing time, lack of success, little skill improvement, lack of fun, boredom, and injury.[123] It has also been shown that young athletes who discontinue participation may reenter the same sport or participate in a different sport in the future.[122]

It is difficult to determine the extent of overtraining/burnout in children and adolescents, in part due to the lack of standard terminology used in different studies. Overreaching was found to occur in 30% to 35% of adolescent athletes.[185–187] One-third of young English athletes in 19 different sports experienced overreaching at least once.[185] Thirty-five percent of adolescent swimmers from 4 countries reported having felt "stale" in a questionnaire.[186]

There are multiple risk factors for young athletes developing overtraining/burnout. Table 5 lists the environmental factors and personal characteristics. Among elite young athletes there is a higher incidence in females, athletes in individual sports, and those competing at the highest level of their sport.[185,187] It is not clear if age is a risk factor.

Single sport intensive training is another potential risk factor. Several studies have suggested that athletes who had early specialized training withdrew from their sport either due to injury or burnout from the sport.[189–191] Swimmers who specialized early spent less time on the national team and retired from swimming earlier than athletes who specialized later.[189] Early specialization also seems to be correlated with reports of decreased general health and psychological well-being.[134,190]

The diagnosis of overtraining syndrome/burnout can only be made by taking a thorough history and requires the recognition of nonspecific and varied symptomatology in athletes (Table 6). Table 7 outlines important historical features. Laboratory studies and other tests should only be performed if indicated by the history.

Treatment of overtraining syndrome/burnout depends on the etiology for the specific young athlete. Any diagnosed organic disease should be treated appropriately. Rest or relative rest is an important component of the treatment plan. Prevention of attrition is possible by changing adult-controlled factors. Efforts should also be made to develop realistic but positive perceptions of competence in young athletes.[122] One difference in children compared with adults is that there appears to be more of a psychological component to burnout and attrition with adult-supervised activities. Consultation with a mental health expert (ie, sport psychologist) should be considered due to this aspect in young athletes. Treatment of depression, anxiety, and sleep disturbances should initially be addressed with nonpharmacological methods. Pharmacologic agents may be implemented with appropriate consultant guidance.

CONSIDERATIONS FOR OVERUSE INJURY PREVENTION

Studies demonstrating successful overuse injury prevention methods are limited. Given the prior discussion, this section (and the summary that follows) will summarize recommendations based upon the available data using the Strength of Recommendation Taxonomy (SORT) grading system[193] (Table 8).

Training Workload

As discussed above, overuse injury in youth has been shown to be related to higher workloads, including training volume and intensity.

- Limiting weekly and yearly participation time, limits on sport-specific repetitive movements (eg, pitch count limits), and scheduled rest periods are recommended. (B)
- Such modifications need to be individualized based upon the sport and the athlete's age, growth rate, readiness, and injury history. (C)
- Careful monitoring of training workload during the adolescent growth spurt is recommended, as injury risk seems to be greater during this phase. (B) The apparent increased risk may be related to a number of factors including diminished size-adjusted bone mineral density, asynchronous growth patterns, relative weakness of growth cartilage, and physeal vascular susceptibility.

TABLE 5. Factors Related to Burnout in Young Athletes[184,187,188]

Environmental Factors
Extremely high training volumes
Extremely high time demands
Demanding performance expectations (imposed by self or significant other)
Frequent intense competition
Inconsistent coaching practices
Little personal control in sport decision making
Negative performance evaluations (critical instead of supportive)
Personal Characteristics
Perfectionism
Need to please others
Nonassertiveness
Unidimensional self-conceptualization (focusing only on one's athletic involvement)
Low self-esteem
High perception of stress (high anxiety)

TABLE 6. Symptoms of Overtraining Syndrome/Burnout[180,187,188]

Fatigue	Insomnia	Loss of appetite
Depression	Irritability	Weight loss
Bradycardia or tachycardia	Agitation	Lack of mental concentration
Loss of motivation or interest	Decreased self-confidence	Heavy, sore, stiff muscles
Hypertension	Anxiety	Restlessness
Sleep disturbances	Nausea	Frequent illness

Strength and Conditioning

Strength gains, injury prevention, injury rehabilitation, enhanced long-term health, and improved sport performance are all potential benefits of youth strength training.[194–198]

- Preseason conditioning programs can reduce injury rates in young athletes. (B)[199–202]
- In addition, prepractice neuromuscular training can reduce lower extremity injuries. (B)[203–205]

Regular participation in a resistance training program can improve bone health and body composition and potentially reduce sport-related injuries.[197,206–208] It is now well established that with proper supervision and planning, such training programs can be performed safely in the pediatric population.[196,198]

Equipment

During periods of rapid growth and development, equipment size and fit can change dramatically and necessitate frequent evaluation.

- Although data are lacking that link such issues to overuse injury, given the altered biomechanics that may

TABLE 7. Diagnosis of Overtraining Syndrome/Burnout[180,192]

History
Decreased performance persisting despite weeks to months of recovery
Disturbances in mood
Lack of signs/symptoms or diagnosis of other possible causes of underperformance
Lack of enjoyment participating in sport
Inadequate nutritional and hydration intake
Presence of potential triggers: (a) increased training load with adequate recovery, (b) monotony of training, (c) excessive number of competitions, (d) sleep disturbance, (e) stressors in family life (parental pressure), (f) stressors in sporting life (coaching pressure and travel demands), (g) previous illness.
Testing (if indicated by history)
Consider laboratory studies: complete blood count, comprehensive metabolic panel, erythrocyte sedimentation rate, C-reactive protein, iron studies, creatine kinase, thyroid studies, cytomegalovirus and Ebstein-Barr virus titers.
Profile of Mood States (POMS): A psychometric tool for a global measure of mood, tension, depression, anger, vigor, fatigue, and confusion.[169]

TABLE 8. Strength-of-Recommendation Taxonomy (SORT)[193]

Strength of Recommendation	Basis for Recommendation
A	Consistent, good-quality, patient-oriented evidence
B	Inconsistent or limited-quality patient-oriented evidence
C	Consensus, disease-oriented evidence, usual practice, expert opinion, or case series for studies of diagnosis, treatment, prevention, or screening

occur with ill-fitting equipment, proper sizing and resizing of equipment is recommended. (C)

Burnout

Measures to prevent burnout from sports should include avoidance of both overscheduling and excessive time commitment to sport.

- To reduce the likelihood of burnout in youth sports, an emphasis should be placed on skill development over competition and winning. (C)

SUMMARY AND RECOMMENDATIONS

Overuse injuries are common in children and adolescents participating in sports, particularly for those participating on a nearly continuous yearly schedule. In young athletes these injuries are the result of a complex interaction of multiple factors, including growth-related factors that are unique to this population. Although often thought to be self-limited injuries, recovery time can be lengthy, often more so than acute injuries. In addition, some overuse injuries have the potential to negatively affect future participation, and may result in long-term health consequences. Further, in the setting of competitive youth sports, the specter of burnout is also a concern. It is thus essential that health care providers provide comprehensive evaluation and treatment of young athletes with overuse injuries and/or those who exhibit features of burnout.

In addition to the recommendations regarding prevention, the following summary statements are made:

1. Overuse injuries are underreported in the current literature because most injury definitions have focused on time loss from sport. (B)
2. Preparticipation exams may identify prior injury patterns and provide an opportunity to assess sport readiness. (C)
3. A history of prior injury is an established risk factor for overuse injuries and should be noted as part of each injury assessment. (A)
4. Adolescent female athletes should be assessed for menstrual dysfunction as a potential predisposing factor to overuse injury. (B)
5. Parents and coaches should be educated regarding the concept of sport readiness. (C) Variations in cognitive development, as well as motor skills, should be considered when setting goals and expectations.
6. Early sport specialization may not lead to long-term success in sports and may increase risk for overuse injury and burnout. With the exception of early entry sports such as gymnastics, figure skating, and swimming/diving, sport diversification should be encouraged at younger ages. (C)
7. When an overuse injury is diagnosed, it is essential to address the underlying cause(s). (C) The athlete, parents, and coaches should be involved in reviewing all risk factors and developing a strategy to attempt to avoid recurrent injury.
8. All overuse injuries are not inherently benign. (A) Clinicians should be familiar with specific high-risk injuries, including stress fractures of the femoral neck, tarsal navicular, anterior tibial cortex and physis, and effort thrombosis.

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REFERENCES

1. National Federation of State High School Association. 2011-12 high school athletics participation survey. http://www.nfhs.org/. Accessed May 10, 2013.
2. Sporting Goods Manufacturers Association Research/Sports Marketing Surveys USA. *U.S. Trends in Team Sports Report, 2011*. Jupiter, FL: Updated May 2011. http://www.sfia.org/reports/280_2011-U.S-Trends-in-Team-Sports-Report. Accessed December 5, 2013.
3. Little League Online. *Little League Around the World, Leagues and Participants Since 1939*. http://www.littleleague.org/learn/about/historyandmission/aroundtheworld.htm. Accessed May 20, 2013.
4. American Youth Soccer Organization. http://www.ayso.org/AboutAYSO/history.aspx. Accessed January 9, 2013.
5. National Council of Youth Sports. Report on trends and participation in organized youth sports 2008. http://www.ncys.org/pdfs/2008/2008-ncys-market-research-report.pdf. Accessed May 10, 2013.
6. Hyman M. *The Most Expensive Game in Town. The Rising Cost of Youth Sports and the Toll on Today's Families*. Boston, MA: Beacon Press; 2012.
7. Luke A, Lazaro RM, Bergeron MF, et al. Sports-related injuries in youth athletes: is overscheduling a risk factor? *Clin J Sport Med.* 2011;21:307–314.
8. Outerbridge AR, Micheli LJ. Overuse injuries in the young athlete. *Clin Sports Med.* 1995;14:503–516.
9. Yang J, Tibbetts AS, Covassin T, et al. Epidemiology of overuse and acute injuries among competitive collegiate athletes. *J Athl Train.* 2012;47:198–204.
10. Rae K, Orchard J. The Orchard Sports Injury Classification System (OSICS) version 10. *Clin J Sport Med.* 2007;17:201–204.
11. Le Gall F, Carling C, Reilly T, et al. Incidence of injuries in elite French youth soccer players: a 10-season study. *Am J Sports Med.* 2006;34:928–938.
12. Orava S, Puranen J. Exertion injuries in adolescent athletes. *Br J Sports Med.* 1978;12:4–10.
13. Caine D, DiFiori J, Maffulli N. Physeal injuries in children's and youth sports: reasons for concern? *Br J Sports Med.* 2006;40:749–760.
14. DiFiori JP. Overuse injury of the physis: a "growing" problem. *Clin J Sport Med.* 2010;20:336–337.
15. DiFiori JP. Evaluation of overuse injuries in children and adolescents. *Curr Sports Med Rep.* 2010;9:372–378.
16. Witvrouw E, Lysens R, Bellemans J, et al. Intrinsic risk factors for the development of anterior knee pain in an athletic population. A two-year prospective study. *Am J Sports Med.* 2000;28:480–489.

17. Carson WG Jr, Gasser SI. Little Leaguer's shoulder. A report of 23 cases. *Am J Sports Med.* 1998;26:575–580.
18. Osbahr DC, Kim HJ, Dugas JR. Little League shoulder. *Curr Opin Pediatr.* 2010;22:35–40.
19. DiFiori JP, Caine DJ, Malina RM. Wrist pain, distal radial physeal injury, and ulnar variance in the young gymnast. *Am J Sports Med.* 2006;34:840–849.
20. McBain K, Shrier I, Shultz R, et al. Prevention of sports injury I: a systematic review of applied biomechanics and physiology outcomes research. *Br J Sports Med.* 2012;46:169–173.
21. Caine D, Maffulli N, Caine C. Epidemiology of injury in child and adolescent sports: injury rates, risk factors, and prevention. *Clin Sports Med.* 2008;27:19–50, vii.
22. Mickalide AD, Hansen LM. Coaching our kids to fewer injuries: a report on youth sports safety. In: Worldwide SK, ed. Washington, DC: Safe Kids Worldwide; 2012. www.safekids.org/assets/docs/safety-basics/sports/2012-sports.pdf. Accessed January 9, 2013.
23. Comstock D, Collins CL, McIlvain NM. Summary report, National High School Sports-Related Injury Surveillance Study 2010-2011 school year. www.nationwidechildrens.org/Document/Get/103354. Accessed May 10, 2013.
24. Watkins J, Peabody P. Sports injuries in children and adolescents treated at a sports injury clinic. *J Sports Med Phys Fitness.* 1996;36:43–48.
25. Clarsen B, Myklebust G, Bahr R. Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology: the Oslo Sports Trauma Research Centre (OSTRC) overuse injury questionnaire. *Br J Sports Med.* 2013;47:495–502.
26. Valovich McLeod TC, Decoster LC, Loud KJ, et al. National Athletic Trainers' Association position statement: prevention of pediatric overuse injuries. *J Athl Train.* 2011;46:206–220.
27. Brenner JS. Overuse injuries, overtraining, and burnout in child and adolescent athletes. *Pediatrics*. 2007;119:1242–1245.
28. Bergeron MF. Youth sports in the heat: recovery and scheduling considerations for tournament play. *Sports Med.* 2009;39:513–522.
29. Aagaard H, Jorgensen U. Injuries in elite volleyball. *Scand J Med Sci Sports.* 1996;6:228–232.
30. Baxter-Jones A, Maffulli N, Helms P. Low injury rates in elite athletes. *Arch Dis Child.* 1993;68:130–132.
31. Shankar PR, Fields SK, Collins CL, et al. Epidemiology of high school and collegiate football injuries in the United States, 2005-2006. *Am J Sports Med.* 2007;35:1295–1303.
32. Bergstrom KA, Brandseth K, Fretheim S, et al. Back injuries and pain in adolescents attending a ski high school. *Knee Surg Sports Traumatol Arthrosc.* 2004;12:80–85.
33. Tenforde AS, Sayres LC, McCurdy ML, et al. Overuse injuries in high school runners: lifetime prevalence and prevention strategies. *PM R.* 2011;3:125–131.
34. Moller M, Attermann J, Myklebust G, et al. Injury risk in Danish youth and senior elite handball using a new SMS text messages approach. *Br J Sports Med.* 2012; 46:531–537.
35. Lysens RJ, Ostyn MS, Vanden Auweele Y, et al. The accident-prone and overuse-prone profiles of the young athlete. *Am J Sports Med.* 1989;17:612–619.
36. Malina RM. Physical growth and biological maturation of young athletes. *Exerc Sport Sci Rev.* 1994;22:389–433.
37. Carter CW, Micheli LJ. Training the child athlete: physical fitness, health and injury. *Br J Sports Med.* 2011;45:880–885.
38. Bahr R, Holme I. Risk factors for sports injuries-a methodological approach. *Br J Sports Med.* 2003;37:384–392.
39. Meeuwisse WH. Assessing causation in sport injury: a multifactorial model. *Clin J Sport Med.* 1994;4:166–170.
40. Sciascia A, Kibler WB. The pediatric overhead athlete: what is the real problem? *Clin J Sport Med.* 2006:16;471–477.
41. Pringle RG, McNair P, Stanley S. Incidence of sporting injury in New Zealand youths aged 6–15 years. *Br J Sports Med.* 1998;32:49–52.
42. Rauh MJ, Margherita AJ, Rice SG, et al. High school cross country running injuries: a longitudinal study. *Clin J Sport Med.* 2000;10:110–116.
43. Caine D, Knutzen K, Howe W, et al. A three-year epidemiological study of injuries affecting young female gymnasts. *Phys Therap Sport.* 2003;4:10–23.
44. Schulz MR, Marshall SW, Mueller FO, et al. A prospective cohort study of injury incidence and risk factors in North Carolina high school competitive cheerleaders. *Am J Sports Med.* 2004;32:396–405.
45. Turbeville SD, Cowan LD, Owen WL, et al. Risk factors for injury in high school football players. *Am J Sports Med.* 2003;31:974–980.
46. Emery CA, Meeuwisse WH, Hartmann SE. Evaluation of risk factors for injury in adolescent soccer. Implementation and validation of an injury surveillance system. *Am J Sports Med.* 2005;33:1882–1891.
47. Kucera KL, Marshall SW, Kirkendall DT, et al. Injury history as a risk factor for incident injury in youth soccer. *Br J Sport Med.* 2005;39:462–466.
48. Caine D, Daly RM, Jolly D, et al. Risk factors for injury in young competitive female gymnasts. *Br J Sports Med.* 2006;40:91–92.
49. Ramirez M, Brown Schaffer B, Shen H, et al. Injuries to high school football athletes in California. *Am J Sports Med.* 2006;34:1147–1158.
50. Buist I, Bredeweg SW, Lemmink KA, et al. Predictors of running-related injuries in novice runners enrolled in a systematic training program: a prospective cohort study. *Am J Sports Med.* 2010;38:273–280.
51. Bouchard C, Malina RM, Perusse L. *Genetics of Fitness and Physical Performance*. Champaign, IL: Human Kinetics; 1997.
52. Hyun E. *Making Sense of Developmentally and Culturally Appropriate Practice (DCAP) in Early Childhood Education*. New York, NY: Peter Lang, Chapter 2; 1998.
53. Malina RM, Bouchard C. *Growth, Maturation, and Physical Activity*. Champaign, IL: Human Kinetics; 1991.
54. Dalton SE. Overuse injuries in adolescent athletes. *Sports Med.* 1992; 13;58–70.
55. Caine D, Roy S, Singer KM, et al. Stress changes of the distal radial growth plate. A radiographic survey and review of the literature. *Am J Sports Med.* 1992;20:290–298.
56. Alexander CJ. Effects of growth rate on the strength of the growth plate-shaft junction. *Skel Radiol.* 1976;1:67–76.
57. Bright RW, Burstein AH, Elmore SM. Epiphyseal-plate cartilage: a biomechanical and histological analysis of failure modes. *J Bone Joint Surg.* 1974;56A;688–703.
58. Flachsmann R, Broom ND, Hardy AE, et al. Why is the adolescent joint particularly susceptible to osteochondral shear fracture? *Clin Orthop Relat Res.* 2000;381:212–221.
59. Bailey DA, Wedge JH, McCulloch RG, et al. Epidemiology of fractures of the distal end of the radius in children associated with growth. *J Bone Joint Surg Am.* 1989;71A:1225–1231.
60. Blimkie CJ, Lefevre J, Beunen GP, et al. Fractures, physical activity, and growth velocity in adolescent Belgian boys. *Med Sci Sports Exerc.* 1993;25:801–808.
61. DiFiori JP, Puffer JC, Aish B, et al. Wrist pain in young gymnasts: frequency and effects upon training over 1 year. *Clin J Sport Med.* 2002;12:348–353.
62. Niemeyer P, Weinberg A, Schmitt H, et al. Stress fractures in the juvenile skeletal system. *Int J Sports Med.* 2006;27:242–249.
63. Duggleby T, Kumar S. Epidemiology of juvenile low back pain: a review. *Disabil Rehabil.* 1997:19;505–512.
64. Faulkner RA, Davidson KS, Bailey DA, et al. Size-corrected BMD decreases during peak linear growth: implications for fracture incidence during adolescence. *J Bone Min Res.* 2006;21:1864–1870.
65. Maffulli N. Intensive training in young athletes. The orthopaedic surgeon's viewpoint. *Sports Med.* 1990;9:229–243.
66. Jackowski SA, Faulkner RA, Farthing JP, et al. Peak lean tissue mass accrual precedes changes in bone strength indices at the proximal femur during the pubertal growth spurt. *Bone*. 2009;44:1186–1190.
67. Quatman CE, Ford KR, Myer GD, et al. The effects of gender and pubertal status on generalized joint laxity in young athletes. *J Sci Med Sport.* 2008;11:257–263.
68. Falciglia F, Guzzanti V, Di Ciommo V, et al. Physiological knee laxity during pubertal growth. *Bull NYU Hosp Jt Dis.* 2009;67:325–329.
69. Hawkins D, Metheny J. Overuse injuries in youth sports: biomechanical considerations. *Med Sci Sports Exerc.* 2001;33:1701–1710.
70. Jaramillo D, Laor T, Zaleske DJ. Indirect trauma to the growth plate. Results of MR imaging after epiphyseal and metaphyseal injury in rabbits. *Radiology*. 1993;187:171–178.
71. Shih C, Chang CY, Penn IW, et al. Chronically stressed wrists in adolescent gymnasts: MR imaging appearance. *Radiology*. 1995;195:855–859.

72. DiFiori JP, Mandelbaum BR. Wrist pain in a young gymnast: unusual radiographic findings and MRI evidence of growth plate injury. *Med Sci Sports Exerc.* 1996;28:1453–1458.
73. Myer GD, Ford KR, Barber Foss KD, et al. The incidence and potential pathomechanics of patellofemoral pain in female athletes. *Clin Biomech (Bristol, Avon).* 2010;25;700–707.
74. Rauh MJ, Koepsell TD, Rivara FP, et al. Quadriceps angle and risk of injury among high school cross-country runners. *J Orthop Sports Phys Ther.* 2007:37;725–733.
75. Thomis M, Claessens AL, Lefevre J, et al. Adolescent growth spurts in female gymnasts. *J Pediatr.* 2005;146:239–244.
76. Pacey V, Nicholson LL, Adams RD, et al. Generalized joint hypermobility and risk of lower limb joint injury during sport: a systematic review with meta-analysis. *Am J Sports Med.* 2010;38:1487–1497.
77. Konopinski MD, Jones GJ, Johnson MI. The effect of hypermobility on the incidence of injuries in elite-level professional soccer players: a cohort study. *Am J Sports Med.* 2012;40:763–769.
78. Ilahi OA, Kohl HW III. Lower extremity morphology and alignment and risk of overuse injury. *Clin J Sport Med.* 1998;8:38–42.
79. Wen DY. Risk factors for overuse injuries in runners. *Curr Sports Med Rep.* 2007;6:307–313.
80. Noehren B, Davis I, Hamill J. ASB clinical biomechanics award winner 2006 prospective study of the biomechanical factors associated with iliotibial band syndrome. *Clin Biomech (Bristol, Avon).* 2007;22:951–956.
81. Ghani Zadeh Hesar N, Van Ginckel A, Cools A, et al. A prospective study on gait-related intrinsic risk factors for lower leg overuse injuries. *Br J Sports Med.* 2009;43:1057–1061.
82. MacLean CL, Davis IS, Hamill J. Short and long-term influences of a custom foot orthotic intervention on lower extremity dynamics. *Clin J Sport Med.* 2008:18;338–343.
83. Micheli LJ. Overuse injuries in children's sports: the growth factor. *Orthop Clin North Am.* 1983;14:337–360.
84. Feldman D, Shrier I, Rossignol M, et al. Adolescent growth is not associated with changes in flexibility. *Clin J Sport Med.* 1999;9:24–29.
85. Ortega FB, Artero EG, Ruiz JR, et al. Physical fitness levels among European adolescents: the HELENA study. *Br J Sports Med.* 2011;45:20–29.
86. Catley MJ, Tomkinson GR. Normative health-related fitness values for children: analysis of 85347 test results on 9-17-year-old Australians since 1985. *Br J Sports Med.* 2013;47:98–108.
87. Hart L. Effect of stretching on sport injury risk: a review. *Clin J Sport Med.* 2005;15:113.
88. Jamtvedt G, Herbert RD, Flottorp S, et al. A pragmatic randomised trial of stretching before and after physical activity to prevent injury and soreness. *Br J Sports Med.* 2010;44:1002–1009.
89. Sabick MB, Kim YK, Torry MR, et al. Biomechanics of the shoulder in youth baseball pitchers: implications for the development of proximal humeral epiphysiolysis and humeral retrotorsion. *Am J Sports Med.* 2005;33:1716–1722.
90. Clement DB, Taunton JE, Smart GW. Achilles tendonitis and peritendonitis: etiology and treatment. *Am J Sports Med.* 1984;12:179–184.
91. Ellenbecker T, Roetert EP. Age specific isokinetic glenohumeral internal and external rotation strength in elite junior tennis players. *J Sci Med Sport.* 2003;6:63–70.
92. Borsa PA, Laudner KG, Sauers EL. Mobility and stability adaptations in the shoulder of the overhead athlete: a theoretical and evidence-based perspective. *Sports Med.* 2008:38;17–36.
93. Stull JD, Philippon MJ, LaPrade RF. "At-risk" positioning and hip biomechanics of the Peewee ice hockey sprint start. *Am J Sports Med.* 2011;39(suppl):29S–35S.
94. Anderson LB, Harro M, Sardinha LB, et al. Physical activity and clustered cardiovascular risk in children: a cross-sectional study (The European Youth Heart Study). *Lancet.* 2006;368:299–304.
95. Strong WB, Malina RM, Blimkie CJ, et al. Evidence based physical activity for school-age youth. *J Pediatr.* 2005;146:732–737.
96. Resaland GK, Mamen A, Boreham C, et al. Cardiovascular risk factor clustering and its association with fitness in nine-year-old rural Norwegian children. *Scand J Med Sci Sports.* 2010;20:e112–e120.
97. Emery CA, Cassidy JD, Klassen TP, et al. Effectiveness of a home-based balance-training program in reducing sports-related injuries among healthy adolescents: a cluster randomized controlled trial. *CMAJ.* 2005;172:749–754.
98. Emery CA, Rose MS, McAllister JR, et al. A prevention strategy to reduce the incidence of injury in high school basketball: a cluster randomized controlled trial. *Clin J Sport Med.* 2007;17:17–24.
99. Bennell KL, Malcolm SA, Thomas SA, et al. Risk factors for stress fractures in track and field athletes: a twelve month prospective study. *Am J Sports Med.* 1996;24:810–818.
100. Herman K, Barton C, Malliaras P, et al. The effectiveness of neuromuscular warm-up strategies, that require no additional equipment, for preventing lower limb injuries during sports participation: a systematic review. *BMC Med.* 2012;10:75.
101. Shaffer RA, Rauh MJ, Brodine SK, et al. Predictors of stress fracture susceptibility in young female recruits. *Am J Sports Med.* 2006;34;108–115.
102. Barrow GW, Saha S. Menstrual irregularity and stress fractures in collegiate female distance runners. *Am J Sports Med.* 1988;16:209–216.
103. Friedl KE, Nuovo JA, Patience TH, et al. Factors associated with stress fracture in young army women: indications for further research. *Mil Med.* 1992;157:334–338.
104. Myburgh KH, Hutchins J, Fataar AB, et al. Low bone density is an etiologic factor for stress fractures in athletes. *Ann Intern Med.* 1990;113:754–759.
105. Rauh MJ, Macera CA, Trone DW, et al. Epidemiology of stress fracture and lower-extremity overuse injury in female recruits. *Med Sci Sports Exerc.* 2006;38:1571–1577.
106. Cobb KL, Bachrach LK, Greendale G, et al. Disordered eating, menstrual irregularity, and bone mineral density in female runners. *Med Sci Sports Exerc.* 2003;35:711–719.
107. Nattiv A, Loucks AB, Manore MM, et al. American College of Sports Medicine position stand. The female athlete triad. *Med Sci Sports Exerc.* 2007;39:1867–1882.
108. Cobb KL, Bachrach LK, Sowers M, et al. The effect of oral contraceptives on bone mass and stress fractures in female runners. *Med Sci Sports Exerc.* 2007;39:1464–1473.
109. Olsen SJ II, Fleisig GS, Dun S, et al. Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. *Am J Sports Med.* 2006;34;905–912.
110. Rose MS, Emery CA, Meeuwisse WH. Sociodemographic predictors of sports injury in adolescents. *Med Sci Sports Exerc.* 2008;40:444–450.
111. Fleisig GS, Andrews JR, Cutter GR, et al. Risk of serious injury for young baseball pitchers: a 10-year prospective study. *Am J Sports Med.* 2011;39:253–257.
112. Emery C. Risk factors for injury in child and adolescent sport. *Clin J Sport Med.* 2003;13:256–268.
113. Loud KJ, Gordon CM, Micheli LJ, et al. Correlates of stress fractures among preadolescent and adolescent girls. *Pediatrics*. 2005;115:e399–e406.
114. Ohta-Fukushima M, Mutoh Y, Takasugi S, et al. Characteristics of stress fractures in young athletes under 20 years. *J Sports Med Phys Fitness.* 2002;42:198–206.
115. Lyman S, Fleisig GS, Waterbor JW, et al. Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Med Sci Sports Exerc.* 2001;33:1803–1810.
116. Lyman S, Fleisig GS, Andrews JR, et al. Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. *Am J Sports Med.* 2002;30:463–468.
117. DiFiori JP, Puffer JC, Mandelbaum BR, et al. Factors associated with wrist pain in the young gymnast. *Am J Sports Med.* 1996;24:9–14.
118. Parks ED, Ray TR. Prevention of overuse injuries in young baseball pitchers. *Sports Health*. 2009;1:514–517.
119. Dun S, Loftice J, Fleisig GS, et al. A biomechanical comparison of youth baseball pitches: is the curveball potentially harmful? *Am J Sports Med.* 2008;36:686–692.
120. Dennis RJ, Finch CF, Farhart PJ. Is bowling workload a risk factor for injury to Australian junior cricket fast bowlers? *Br J Sports Med.* 2005;39:843–846.
121. Cuff S, Loud K, O'Riordan MA. Overuse injuries in high school athletes. *Clin Pediatr.* 2010;49:731–736.
122. Gould D. Understanding attrition in children's sport. In: Gould D, Weiss MR, eds. *Advances in Pediatric Sport Sciences*. Champaign, IL: Human Kinetics Publishers Inc; 1987:61–86.
123. Malina RM. Readiness for competitive youth sport. Chapter 7. In: Weiss MR, Gould D, eds. *Sport for Children and Youths*. Champaign, IL: Human Kinetics Publishers, Inc; 1986:45–50.

124. Magill RA. Critical periods: relation to youth sports. In: *Children in Sport Human*. Champaign, IL: Kinetics Publishers, Inc; 1982:38–47.
125. Weiss MR. A theoretical overview of competence motivation. In: Weiss MR, Gould D, eds. *Sport for Children and Youths*. Champaign, IL: Human Kinetics Publishers, Inc; 1986:75–88.
126. Harris SS. Readiness to participate in sports. In: *Care of the Young Athlete*. 2nd ed. Anderson S, Harris SS, eds. American Academy of Pediatrics; 2010:9–15.
127. Seefeldt V. The concept of readiness applied to motor skill acquisition. In: *Children in Sport*. Champaign, IL: Human Kinetics Publishers, Inc; 1982:31–37.
128. Nelson MA. Developmental skills and children's sports. *Phys Sportsmed.* 1991;19:67–79.
129. Marshall WA, Tanner JM. Variations in the pattern of pubertal changes in boys. *Arch Dis Child.* 1970;45:13–23.
130. Aicinena S. Youth sport readiness: a predictive model for success. *Phys Educator.* 1992;49:58–67.
131. Balyi I, Hamilton A. Long-term athlete development: trainability in childhood and adolescence. *Natl Coaching Inst Br Columbia, Can.* 2004.
132. Jayanthi N, Pinkham C, Dugas L, et al. Sports specialization in young athletes: evidence-based recommendations. *Sports Health*. 2013;5:251–257.
133. Hume PA, Hopkins WG, Robinson DM, et al. Predictors of attainment in rhythmic sportive gymnastics. *J Sports Med Phys Fitness.* 1994;33:367–377.
134. Law M, Côté J, Ericsson KA. Characteristics of expert development in rhythmic gymnastics: a retrospective study. *Int J Exerc Sport Psychol.* 2007;5:82–103.
135. Moesch K, Elbe AM, Hauge ML, et al. Late specialization: the key to success in centimeters, grams, or seconds (cgs) sports. *Scand J Med Sci Sports.* 2011;21:e282–e290.
136. Abernethy B, Baker J, Côté J. Transfer of pattern recall skills may contribute to the development of sport expertise. *Appl Cognit Psychol.* 2005;19:705–718.
137. Jayanthi N, O'Boyle J, Durazo-Arvizu R. Risk factors for medical withdrawals in United States Tennis Association Junior National tennis tournaments: a descriptive epidemiologic study. *Sports Health*. 2009;1:231–235.
138. Jayanthi NA, Dechert A, Durazo R, et al. Training and specialization risks in junior elite tennis players. *J Med Sci Tennis.* 2011;16:14–20.
139. Jayanthi NA, Pinkham C, Durazo-Arivu R, et al. The risks of sports specialization and rapid growth in young athletes. *Clin J Sports Med.* 2011;21:157.
140. Fishman FG, Adams SB, Easley ME, et al. Vascularized pedicle bone grafting for nonunions of the tarsal navicular. *Foot Ankle Int.* 2012;33:734–739.
141. Hulkko A, Orava S. Diagnosis and treatment of delayed and non-union stress fractures in athletes. *Ann Chir Gynaecol.* 1991;80:177–184.
142. Kurd MF, Patel D, Norton R, et al. Nonoperative treatment of symptomatic spondylolysis. *J Spinal Disord Tech.* 2007;20:560–564.
143. Micheli LJ, Wood R. Back pain in young athletes. Significant differences from adults in causes and patterns. *Arch Pediatr Adolesc Med.* 1995;149:15–18.
144. Kobayashi A, Kobayash T, Kato K, et al. Diagnosis of radiographically occult lumbar spondylolysis in young athletes by magnetic resonance imaging. *Am J Sports Med.* 2013;41:169–176.
145. El Rassi G, Takemitsu M, Woratanarat P, et al. Lumbar spondylolysis in pediatric and adolescent soccer players. *Am J Sports Med.* 2005;33:1688–1694.
146. Iwamoto J, Sato Y, Tsuyoshi T, et al. Return to sports activity by athletes after treatment of spondylolysis. *World J Orthop.* 2010;1:26–30.
147. McCleary MD, Congeni JA. Current concepts in the diagnosis and treatment of spondylolyisis in young athletes. *Curr Sports Med Rep.* 2007;6:62–66.
148. Frennered AK, Danielson BI, Nachemson AL. Natural history of symptomatic isthmic low-grade spondylolisthesis in children and adolescents: a seven-year follow-up study. *J Pediatr Orthop.* 1991;11:209–213.
149. Beutler WJ, Fredrickson BE, Murtland A, et al. The natural history of spondylolysis and spondylolisthesis: 45-year follow-up evaluation. *Spine*. 2003;28:1027–1035.
150. Kristen E, Radcliff S, Kalantar B, et al. Surgical management of spondylolysis and spondylolisthesis in athletes: indications and return to play. *Curr Sports Med Rep.* 2009;8:35–40.
151. Maezawa K, Nozawa M, Sugimoto M, et al. Stress fractures of the femoral neck in child with open capital femoral epiphysis. *J Pediatr Orthop B.* 2004;13:407–411.
152. Goolsby MA, Barrack MT, Nattiv A. A displaced femoral neck stress fracture in an amenorrheic adolescent female runner. *Sports Health.* 2012;4:352–356.
153. Lehman R, Shah S. Tension-sided femoral neck stress fracture in a skeletally immature patient. *JBone Joint Surg.* 2004;86:1292–1295.
154. Garcia Mata S, Hidalgo Ovejero A, Martinez Grande M. Transverse stress fracture of the patella in a child. *J Pediatr Orthop B.* 1999;8:208–211.
155. Iwaya T, Takatori Y. Lateral longitudinal stress fracture of the patella: report of three cases. *J Pediatr Orthop.* 1985;5:73–75.
156. Shindle MK, Endo Y, Warren RF, et al. Stress fractures about the tibia, foot, and ankle. *J Am Acad Orthop Surg.* 2012;20:167–176.
157. Varner KE, Younas SA, Lintner DM, et al. Chronic anterior midtibial stress fractures in athletes treated with reamed intramedullary nailing. *Am J Sports Med.* 2005;33:1071–1076.
158. Nyska M. Stress fractures of the medial malleolus, review of the literature and report of a 15-year-old elite gymnast. *Foot Ankle Int.* 2002;23:647–650.
159. Oestreich AE, Bhojwani N. Stress fractures of ankle and wrist in childhood: nature and frequency. *Pediatr Radiol.* 2010;40:1387–1389.
160. Ostlie DK, Simons SM. Tarsal navicular stress fracture in a young athlete: case report with clinical, radiologic, and pathophysiologic correlations. *J Am Board Fam Pract.* 2001;14:381–385.
161. Biedert R, Hintermann B. Stress fractures of the medial great toe sesamoids in athletes. *Foot Ankle Int.* 2003;24:137–141.
162. Dunn A, Campbell RSD, Mayor P, et al. Radiological findings and healing patterns of incomplete stress fractures of the pars interarticularis. *Skeletal Radiol.* 2008;37:443–450.
163. Cahill BR. Stress fracture of the proximal tibial epiphysis: a case report. *Am J Sports Med.* 1977;5:186–187.
164. Godshall RW, Hansen CA, Rising DC. Stress fractures through the distal femoral epiphysis in athletes: a previously unreported entity. *Am J Sports Med.* 1981;9:114–116.
165. Laor T, Wall EJ, Vu LP. Physeal widening in the knee due to stress injury in child athletes. *AJR Am J Roentgenol.* 2006;186:1260–1264.
166. Blatnik TR, Briskin S. Bilateral knee pain in a high-level gymnast. *Clin J Sport Med.* 2013;23:77–79.
167. Green NE, Swiontkowski MF. *Skeletal Trauma in Children*. 3rd ed. Saunders; 2003.
168. Albanese SA, Palmer AK, Kerr DR, et al. Wrist pain and distal growth plate closure of the radius in gymnasts. *J Pediatr Orthop.* 1989;9:23–28.
169. Youri T, Bellemans J, Rombaut L, et al. Is high-impact sports participation associated with bowlegs in adolescent boys? *Med Sci Sport Exerc.* 2012;44:993–998.
170. Wall EJ. Growth plate overuse syndrome of the ankle in athletes. *Med Sci Sport Exerc.* 1997;S29:299.
171. Laor T, Zbojniewicz AM, Eismann EA, et al. Juvenile osteochondritis dissecans: is it a growth disturbance of the secondary physis of the epiphysis? *AJR Am J Roentgenol.* 2012;199:1121–1128.
172. Jans LB, Ditchfield M, Anna G, et al. MR imaging findings and MR criteria for instability in osteochondritis dissecans of the elbow in children. *Eur J Radiol.* 2012;81:1306–1310.
173. Pascual-Garrido C, Moran CJ, Green DW, et al. Osteochondritis dissecans of the knee in children and adolescents. *Curr Opin Pediatr.* 2013;25:46–51.
174. Weiss JM, Jordan SS, Anderson JS, et al. Surgical treatment of unresolved Osgood-Schlatter disease: ossicle resection with tibial tubercleplasty. *J Pediatr Orthop.* 2007;27:844–847.
175. Pihlajamäki HK, Visuri TI. Long-term outcome after surgical treatment of unresolved Osgood-Schlatter disease in young men: surgical technique. *J Bone Joint Surg Am.* 2010;92(suppl 1, pt 2):258–264.
176. Medler RG, McQueen DA. Effort thrombosis in a young wrestler. A case report. *J Bone Joint Surg Am.* 1993;75:1071–1073.
177. Roche-Nagle G, Ryan R, Barry M, et al. Effort thrombosis of the upper extremity in a young sportsman: Paget-Schroetter syndrome. *Br J Sports Med.* 2007;41:540–541.

178. Melby SJ, Vedantham S, Narra VR, et al. Comprehensive surgical management of the competitive athlete with effort thrombosis of the subclavian vein (Paget-Schroetter syndrome). *J Vasc Surg.* 2008;47:809–820.
179. Chang KZ, Likes K, Demos J, et al. Routine venography following transaxillary first rib resection and scalenectomy (FRRS) for chronic subclavian vein thrombosis ensures excellent outcomes and vein patency. *Vasc Endovascular Surg.* 2012;46:15–20.
180. Meeusen R, Duclos M, Gleeson M. Prevention, diagnosis and treatment of the overtraining syndrome. *Eur J Sport Sci.* 2006;6:1–14.
181. Budgett R. Fatigue and underperformance in athletes: the overtraining syndrome. *Br J Sports Med.* 1998;32:107–110.
182. Small E. Chronic musculoskeletal pain in young athletes. *Pediatr Clin North Am.* 2002;49:655–662, vii.
183. Smith RE. Toward a cognitive-affective model of athletic burnout. *J Sport Psychol.* 1986;8:36–50.
184. Gould D. Intensive sport participation and the prepubescent athlete: competitive stress and burnout. In: Cahill BR, Pearl AJ, eds. *Intensive Participation in Children's Sports*. Champaign, IL: Human Kinetics; 1993:19–38.
185. Matos NF, Winsley RJ, Williams CA. Prevalence of nonfunctional overreaching/overtraining in young English athletes. *Med Sci Sports Exerc.* 2011;43:1287–1294.
186. Raglin J, Sawamura S, Alexiou S, et al. Original research training practices and staleness in 13-18-year-old swimmers: a cross-cultural study. *Ped Exerc Sci.* 2000;12:61–70.
187. Winsley R, Matos N. Overtraining and elite young athletes. *Med Sport Sci.* 2011;56:97–105.
188. Malina RM. Early sport specialization: roots, effectiveness, risks. *Curr Sports Med Rep.* 2010;9:364–371.
189. Barynina II, Vaitsekhovskii SM. The aftermath of early sports specialization for highly qualified swimmers. *Fitness Sports Rev Int.* 1992;27:132–133.
190. Wall M, Côté J. Developmental activities that lead to dropout and investment in sport. *Phys Educ Sport Pedagogy.* 2007;12:77–87.
191. Gould D, Udry E, Tuffey S, et al. Burnout in competitive junior tennis players: Pt. 1. A quantitative psychological assessment. *Sport Psychol.* 1996;10:322–340.
192. Morgan WP, Brown DR. Psychological monitoring of overtraining and staleness. *Br J Sports Med.* 1987;21:107–114.
193. Ebell MH, Siwek J, Weiss BD, et al. Strength of recommendation taxonomy (SORT): a patient-centered approach to grading evidence in the medical literature. *Am Fam Physician.* 2004;69:548–556.
194. American Academy of Pediatrics Council on Sports Medicine and Fitness, McCambridge TM, Stricker PR. Strength training by children and adolescents. *Pediatrics*. 2008;121:835–840.
195. Faigenbaum AD, Kraemer WJ, Blimkie CJ, et al. Youth resistance training: updated position statement paper from the National Strength and Conditioning Association. *J Strength Cond Res.* 2009;23(suppl 5):S60–S79.
196. Faigenbaum AD, Myer GD. Resistance training among young athletes: safety, efficacy and injury prevention effects. *Br J Sports Med.* 2010;44:56–63.
197. Faigenbaum AD, Myer GD. Pediatric resistance training: benefits, concerns, and program design considerations. *Curr Sports Med Rep.* 2010:9;161–168.
198. Lloyd RS, Faigenbaum AD, Stone MH, et al. Position statement on youth resistance training: the 2014 International Consensus [published online ahead of print September 20, 2013]. *Br J Sports Med.* 2013. doi:10.1136/bjsports-2013-092952.
199. Cahill B, Griffith E. Effect of preseason conditioning on the incidence and severity of high school football knee injuries. *Am J Sports Med.* 1978;6:180–184.
200. Hejna WF, Rosenberg A, Buturusis DJ, et al. The prevention of sports injuries in high school students through strength training. *Natl Strength Coaches Assoc J.* 1982;4:28–31.
201. Heidt RS Jr, Sweeterman LM, Carlonas RL, et al. Avoidance of soccer injuries with preseason conditioning. *Am J Sports Med.* 2000;28:659–662.
202. Hewett TE, Myer GD, Ford KR. Reducing knee and anterior cruciate ligament injuries among female athletes: a systematic review of neuromuscular training interventions. *J Knee Surg.* 2005;18:82–88.
203. Myer GD, Chu DA, Brent JL, et al. Trunk and hip control neuromuscular training for the prevention of knee joint injury. *Clin Sports Med.* 2008;27:425–438, ix.
204. Soligard T, Myklebust G, Steffen K, et al. Comprehensive warm-up programme to prevent injuries in young female footballers: cluster randomised controlled trial. *BMJ.* 2008;337:a2469.
205. LaBella CR, Huxford MR, Grissom J, et al. Effect of neuromuscular warm-up on injuries in female soccer and basketball athletes in urban public high schools: cluster randomized controlled trial. *Arch Pediatr Adolesc Med.* 2011;165:1033–1040.
206. Myer GD, Faigenbaum AD, Chu DA, et al. Integrative training for children and adolescents: techniques and practices for reducing sports-related injuries and enhancing athletic performance. *Phys Sports Med.* 2011:39;74–84.
207. Myer GD, Wall EJ. Resistance training in the young athlete. *Oper Tech Sports Med.* 2006;14:218–230.
208. Faigenbaum A. Resistance training for children and adolescents: are there health outcomes? *Am J Lifestyle Med.* 2007;1:190–200.

