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Overuse injuries and burnout in youth sports: a position statement from the American Medical Society for Sports Medicine

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Background

Youth sport participation offers many benefits including the development of self-esteem, peer socialisation 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 an 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 (1) assist clinicians in recognising young athletes at risk for overuse injuries and burnout; (2) delineate the risk factors and injuries that are unique to the skeletally immature young athlete; (3) describe specific high-risk overuse injuries that present management challenges and/or can lead to long-term health consequences; (4) summarise the risk factors and symptoms associated with burnout in young athletes; (5) provide recommendations on overuse injury prevention.

Methodology

Medical Subject Headings (MeSHs) and text words were searched on 26 March 2012 from MEDLINE, CINAHL and PsycINFO. The search yielded 953 unique articles. Additional articles were found using cross-referencing. The process was repeated on 10 July 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 article. 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 and 18 years of age participate in *team* sports. The National Council of Youth Sports survey found that 60 million children aged 6–18 years participate in *some form* of organised athletics, with 44 million participating in more than one 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 of the epidemiological studies define injury as requiring a 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 amenorrhoea 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 and 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, 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, 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 specialisation

Sport specialisation may be considered as an intensive, year-round training in a single sport at the exclusion of other sports. There is concern that early sport specialisation may increase the 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 a 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 reporting 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 of the 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 a 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 specialisation may be a factor. Data suggest that athletes who had early specialised training withdrew from their sport due to either an injury or a burnout from the sport. However, not all young athletes who drop out of sports are burned out. Most of the youths who discontinue a sport do so as a result of time conflicts and interest in other activities. Some may re-enter 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 individualised based on 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 programmes 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 under-reported in the current literature because most of the injury definitions have focused on time loss from sport (B). Preparticipation examinations 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 specialisation may not lead to a long-term success in sports, and may increase the 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 socialisation, 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 specialisation and participation in a large number 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) 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 non-scholastic sports may best be projected from data obtained by national sport organisations. 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 USA.² Among specific youth sport organisations, an estimated 2.3 million children play Little League baseball, over 600 000 participate in the America Youth Soccer Organisation and 365 000 play softball.^{3 4} The 2008 National Council of Youth Sports survey found that approximately 60 million children aged 6–18 years participate in some form of organised athletics.⁵ Of these, approximately 44 million participated in more than one sport.⁵ In addition, although there is a paucity of data describing the extent of youth sport participation, it is clear that a large number of children do not limit their sports to a given ‘season’, and are involved throughout the calendar year in organised athletics. An emphasis on competitive success has become widespread, resulting in an 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

selection in the elite team, and therefore exposure to the college recruiting process. Children may also play in more than one team or participate in more than one sport at a given time. It is also important to recognise that children’s sports are a big business.⁶ Coaches, personal trainers, club team organisations, sporting goods manufactures, tournament directors and others have a financial stake in youth sports participation.

Given this trend towards early and multifaceted training, frequent competition and single sport specialisation, 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 the 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, MEDLINE, CINAHL and PsycINFO, were searched on 26 March 2012 to identify potentially relevant articles. 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

Table 1 Search methodology

Search terms	PubMed results	CINAHL results	PsycINFO results
<i>Concepts around sports/athletics</i> ("Athletes" [Mesh] OR "Sports" [Mesh] OR sport*[text word] OR athlete*[text word])	130 431	49 948	15 207
<i>Concepts around injuries/fatigue/burnout</i> ("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
<i>Concepts around overuse/cumulative trauma</i> (overus*[text word] OR cumulative[text word] or "over time" [text word])	160 436	25 300	38 716
<i>Limits to children and human studies</i> (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
<i>Combined UNIQUE CITATIONS from search strategy results by database</i>	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 athlete*) OR AB (sport* OR athlete*)) 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, two 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 years) or School Age (6–12 years) or Adolescence (13–17 years).

to this document were reviewed in full by the authors. The process was repeated on 10 July 2013 in order to review any new articles since the initial search was performed. A total of 208 unique references were ultimately chosen for this paper.

Definition of overuse injury

Although there is no clear consensus on the definition of overuse injury, it is generally recognised 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.

Owing to the ongoing growth and development, the types of overuse injuries that occur in young athletes differ compared with 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 apophysitis 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 symptoms 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 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 standardisation 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 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 a concern that these injuries are increasing.^{27–29} The frequency and type of overuse injuries in elite young athletes vary by sport and by age.³⁰ Sport-related training and conditioning are also factors (eg, resistance training as an adjunct to soccer training) causing injury.³⁰ Overuse and non-contact injuries in American football are 2.6 times more likely to occur at the college level than at the high school level.³¹ In a recent 3-year study of 16 sports at one university, 29.3% of injuries were considered overuse injuries.⁹ Baxter-Jones *et al*³⁰ studied 453 elite young athletes in four 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. Other studies report the prevalence of overuse injury among different youth sports to range from 37% (skiing and handball) to 68% (running).^{32–34}

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 (box 1). 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 recognise 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 and neuromuscular function); whereas others are not (eg, age and gender).³⁸ Finally, in young athletes,

Box 1 Categorisation 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
- Anatomical 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.¹⁵)

characteristics of the developing musculoskeletal system are especially important to consider.

Although little data exist that identify a causal relationship between proposed risk factors and overuse injury, recognising 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 recognise and correct the factors that contributed to the original injury.

Growth and development

Children undergo growth and development at an individual rate. Biological 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 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 mineralisation during the growth spurt, resulting in a 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. 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 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, a 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 the alignment, particularly in runners, is controversial, yet widely used. The use of an orthotic can have a short-term 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 a 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 programmes that emphasise improvement in sport-specific biomechanics.^{89 90} In some cases, it is not clear whether 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 a greater strength in internal rotators is typically seen relative to the non-dominant 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 whether 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, though little data exist at this time. Some potential risk factors that are modifiable include poor endurance and lack of pre-season preparation.^{97–101}

Menstrual irregularity and low energy availability

A history of amenorrhoea, especially in sports that emphasise leanness, is a risk factor for bone stress injury. One study in collegiate female distance runners found a linear relationship between the number of menses per year and risk of stress fracture, with amenorrhoeic runners having the highest risk.¹⁰² Several studies have suggested that a *history* of amenorrhoea is a significant risk factor for stress fractures.^{99 101–105} The proposed mechanism correlates inadequate caloric intake with hypoestrogenaemia, 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 a 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 have been theorised 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 h/week was associated with a significantly increased risk of injury requiring medical care.^{110 113 114}

The volume and intensity of training are 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} In addition, a 10-year prospective analysis of 481 youth baseball pitchers aged 9–14 years found a 3.5 times greater likelihood of suffering an injury, resulting in time loss 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 the number of hours of 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 with older players.¹¹ The frequency was highest early in the season for the younger players, compared with 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 three or less seasons per year.¹²¹

Tournament scheduling and showcases have also been a concern. Repeated same-day exercise has been shown to increase the cardiovascular and thermal strain as well as perception of effort in subsequent activity bouts. Although there are 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 minimise 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 are 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 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, 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 are 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 one leg in order to swing the kicking leg.¹²⁶ However, readiness to learn specific skills cannot be determined by chronological age, body size or biological 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 a good eye tracking before being able to hit a pitched ball.¹²⁸

Cognitive development must occur before the young athlete can participate in most of the organised 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 of the motor skills, the young athlete will follow a predictable and necessary sequence. For example, learning to kick a ball requires four stages: first pushing a ball while standing, then learning to kick a ball with some wind-up, then taking a step or two 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 2–5 (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 children aged 6–9 years (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 children of 10–12 years of age, most of them 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 of the cases. This includes football, basketball, hockey and volleyball.

Thus, there is no simple way to determine whether a child is ready for a particular sport. Four factors should be considered: sport-related skills, knowledge about the sport, motivation and socialisation.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 the activities so that they can participate successfully and have fun.¹²⁶

SPORT SPECIALISATION

Sport specialisation may be considered as intensive, year-round training in a single sport at the exclusion of other sports.¹³² Although the degree of specialisation may occur along a spectrum, there is no consensus about what type of specialised training is most appropriate to develop elite-level skills. In addition, there is debate about whether early specialised training and intensive training volumes are necessary to achieve high skill

levels in sports, or whether beginning more specialised and intensive training during late adolescence is more advantageous. Furthermore, there is a growing concern regarding the potential negative effects of early sports specialisation, including injury and sport burnout.

Although there are many examples of early specialised 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 specialised 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 an elite-level status may be far less than the 10 000 h that some have proposed.^{133–135} More commonly, specialised, 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 specialised training until late adolescence, rather than a specific age, to optimise skill development in most of the sports.

There are theoretical and measurable risks associated with intense, specialised training. Injury rates in high school athletes have a direct relationship to exposure by hours/week.¹¹⁰ Other studies have found increased exposure to be an additional risk for injury such as in youth baseball pitchers who pitch > 8 months/year were 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 specialisation has not been clearly demonstrated. In one 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 with healthy uninjured athletes presenting for sports physicals suggests that more specialised 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 specialised training while controlling for training intensity and year-round training. In addition, it would be worthwhile to evaluate multisport athletes longitudinally compared with specialised athletes at various ages and stages of development to compare the effects of sport diversification with specialisation.

HIGH RISK OVERUSE INJURIES

Some overuse injuries may be described as 'high risk' in that if they are unrecognised 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 (OCD), some apophyseal injuries and effort thrombosis (table 2).

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

Table 2 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 malleolar stress fracture, talar dome osteochondral defect, Talar neck stress fracture	Distal fibular stress fracture
Foot	Tarsal navicular stress fracture, 5th metatarsal proximal diaphyseal stress fracture, sesamoid stress fracture	2nd, 3rd, 4th 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 non-union of medial epicondyle	Medial epicondyle apophysitis
Wrist	Distal radial physeal stress injury	

groups.⁶² Most of them 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 non-union, and result in chronic pain and/or lead to the development of degenerative joint disease. For example, non-union of a stress fracture of the tarsal navicular can lead to degenerative joint disease of 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 (Jones' fracture) and the sesamoids.⁶² (table 2) The incidence and prevalence of these injuries in children are not well described. Overall, delayed union and non-union have been reported to occur in up to 10% of athletic stress fractures.¹⁴¹ Delayed union and non-union 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 the young athletes evaluated for back pain, 48.5% of them were found to have occult spondylolysis.^{143 144} Progression to non-union ranges from 14% to 70%, with those who are untreated or had undergone delayed treatment having the highest rates of non-union. 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 In another series evaluating the outcomes of pars stress fractures in young athletes, the average time needed to return to sport was 5.4 months.¹⁴⁶ The decision regarding rigid antilordotic bracing remains controversial, though most of the athletes 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 paediatric spondylolysis, there was no risk for spondylolisthesis if the injury was unilateral.¹⁴⁹ Surgical pars repair may be indicated for painful spondylolysis with non-union, after 6 months of non-operative treatment and at least

9–12 months of symptoms.¹⁵⁰ Surgical fusion may be indicated for spondylolisthesis >50%, and may be a relative indication for those with persistent radicular or neurological 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 recognised 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, 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 orthopaedic specialist and treated with strict non-weightbearing and/or open reduction with internal fixation just as in adults because of the risk of non-union, progression to a pathological 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 4–6-week period of immobilisation in a long leg cast, but may heal faster than adults. Any displaced fracture or fracture with non-union should be referred for surgical fixation.

Anterior tibia

Anterior cortical tibial stress fractures are tension-sided injuries that have a high risk of non-union. Radiographs may display a defect of the anterior cortex, often referred to as the 'dreaded black line.' If the radiographs are negative, MRI or CT with thin cuts may be helpful in making the diagnosis.¹⁵⁶ In one case series, anterior tibial stress fractures were reported in seven male and four female patients (mean age of 17 years).¹⁵⁷ All patients had failed non-operative 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 one 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 three decades of X-rays from a single paediatric orthopaedic 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 injuries occurred during resumption of weightbearing after cast immobilisation for another injury.¹⁵⁹

The incidence of tarsal navicular fractures in the paediatric 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 were reported in five female athletes with a mean age of 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 the patients. All the 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 are 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 reporting 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 3). As the spine cannot be adequately palpated on examination, history alone is the 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. MRI is the study of choice for early stress fracture diagnosis in most of the situations. A single photon emission CT bone scan is frequently used for diagnosing spondylolysis, though MRI with short TI inversion recovery 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 favour 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 localised on examination.

Treatment of high-risk stress reactions and stress fractures depends on the specific site of the injury. 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 paediatric 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, optimising 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.

Physal stress injury

Physal stress injuries related to participation in sports are known to occur, although injury incidence data are limited. Although most physal 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 these physes may result in leg length discrepancy or angular or rotational malalignment of the affected leg.¹⁶⁵

Perhaps, the most studied physal 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 physal 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, radiographical abnormalities consistent with distal radius physal-stress reaction were described in 10–85% of gymnasts. Two studies indicated ‘abnormal’ positive ulnar radial length discrepancy in 8–20% of the gymnasts. Four studies showed significant correlations between training intensity and ulnar radial length discrepancy, suggesting a dose–response relation. Radiographical

Table 3 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 malleolus
Dorsal/medial foot	Tarsal navicular
Lateral foot	5th metatarsal (Jones')
Plantar great toe	Sesamoids

evidence of distal radial physal arrest involving skeletally immature female gymnasts was reported in four studies. The results support the plausibility that stress-related distal radius physal arrest may occur and lead to the subsequent development of positive ulnar variance, but are not conclusive.^{13 19}

Physal injury of the knee has been described in 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 six athletes, five were treated with 3–5 weeks rest and immobilisation and had resolution of their pain and physal widening at 1–3 months. One athlete continued intense training despite medical advice and developed bilateral genu varum deformities over the following 2 years.¹⁶⁵ Furthermore, 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

Osteochondritis dissecans

The injury to the subchondral bone and articular cartilage of joints may develop in young athletes from overuse or acute trauma. Recent data suggest that 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. OCD typically occurs in the adolescent age group. Joint pain, swelling, limited motion and mechanical symptoms are common. Radiographs may confirm the diagnosis. MRI may be needed for diagnosis if X-rays are not confirmatory. MRI is recommended for staging of OCD lesions with unstable lesions defined as articular fluid tracking behind the lesion.¹⁷² Stable lesions are initially treated non-operatively 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 non-operative management.¹⁷³

Recalcitrant or complicated apophyseal injuries

Most of the 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 non-union is unknown. In addition to non-union, 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. The common presenting symptoms are unilateral arm swelling and discolouration. Case reports of effort thrombosis in adolescent athletes have been published.^{176 177} In one 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 postprocedure. 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 As 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 over-reaching and overtraining. Over-reaching may be functional or non-functional. Non-functional over-reaching is defined as intense training that leads to a longer period of decreased performance than functional over-reaching, but both result in full recovery after a rest period. Non-functional over-reaching is further accompanied by increased psychological and/or neuroendocrinological symptoms.¹⁸⁰ Overtraining syndrome is defined as an extreme non-functional over-reaching, with a longer performance decrement (>2 months), more severe symptomatology and maladaptive physiology, and an additional stressor not explained by other disease.¹⁸¹ It has also been defined as a “series of psychological, physiological and hormonal changes that result in decreased sports performance.”^{182 183}

Burnout has been defined by Smith¹⁸⁴ as a “response to ‘chronic stress’ in which a young athlete ceases to participate in a previously enjoyable activity.” The young athlete withdraws from the sport because they perceive that it is not possible to meet the physical and psychological demands of the sport.¹⁸⁵ 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).¹⁸⁴ In addition, Coakley states that the development of unidimensional self-conceptualisation and lack of control lead to stress and ultimately burnout.¹⁸⁵ The more fun and satisfaction the child perceives, the less anxiety they experience.¹⁸⁵ 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.¹⁸⁵ 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.¹⁸⁵ Although stress in appropriate levels may be beneficial by learning stress-coping skills to use later in life, this has not been studied.¹⁸⁵

Attrition occurs when athletes drop out of their sport either permanently or temporarily. However, it is important to recognise that not all young athletes who drop out are burned out. In fact, most of the young athletes discontinue a sport due to time conflicts and interest in other activities, not because of excessive stress or burnout.¹⁸⁵ 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 re-enter 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

Box 2 Factors related to burnout in young athletes^{185 188 207}**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
 Non-assertiveness
 Unidimensional self-conceptualisation (focusing only on one's athletic involvement)
 Low self-esteem
 High perception of stress (high anxiety)

terminology used in different studies. Over-reaching was found to occur in 30–35% of adolescent athletes.^{186–188} One-third of young English athletes in 19 different sports experienced over-reaching at least once.¹⁸⁹ Thirty-five per cent of adolescent swimmers from four countries reported having felt 'stale' in a questionnaire.¹⁸⁷

There are multiple risk factors for young athletes developing overtraining/burnout. Box 2 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.^{186 188} It is not clear whether age is a risk factor.

Single sport, intensive training is another potential risk factor. Several studies have suggested that athletes who had early specialised training withdrew from their sport due to either an injury or a burnout from the sport.^{181 190 191} Swimmers who specialised early spent less time on the national team and retired from swimming earlier than athletes who specialised later.¹⁹⁰ Early specialisation also seems to be correlated with reports of decreased general health and psychological well-being.^{134 181}

The diagnosis of overtraining syndrome/burnout can only be made by taking a thorough history and requires the recognition of non-specific and varied symptomatology in athletes (table 4). Box 3 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 aetiology for the specific young athlete. Any diagnosed organic

Table 4 Symptoms of overtraining syndrome/burnout^{180 188 207}

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

Box 3 Diagnosis of overtraining syndrome/ burnout^{180 208}**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 Epstein-Barr virus titres.

Profile of Mood States (POMS): a psychometric tool for a global measure of mood, tension, depression, anger, vigour, fatigue and confusion.¹⁷⁹

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 non-pharmacological methods. Pharmacological 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 summarise recommendations based on the available data using the Strength of Recommendation Taxonomy (SORT) grading system¹⁹² (table 5).

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 individualised based on 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

Table 5 Strength of Recommendation Taxonomy (SORT)¹⁹²

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

size-adjusted bone mineral density, asynchronous growth patterns, relative weakness of growth cartilage and physal vascular susceptibility.

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.^{189 193–196}

- ▶ Preseason conditioning programmes can reduce injury rates in young athletes (B).^{197–200}
- ▶ In addition, prepractice neuromuscular training can reduce lower extremity injuries (B).^{201–203}

Regular participation in a resistance training programme can improve bone health, body composition and potentially reduce sport-related injuries.^{195 204–206} It is now well established that, with proper supervision and planning, such training programmes can be performed safely in the paediatric population.^{194–196}

Equipment

During the 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 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 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. Furthermore, in the setting of competitive youth sports, the specter of burnout is also a concern. It is thus essential that healthcare 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 under-reported in the current literature because most of the injury definitions have focused on time loss from sport (B).
2. Preparticipation examinations 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 specialisation 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 10 May 2013).
- 2 Sporting Goods Manufacturers Association Research/Sports Marketing Surveys USA. U.S. Trends in Team Sports Report. Jupiter, FL, 2011. Updated May 2011. http://www.sfia.org/reports/280_2011-U.S-Trends-in-Team-Sports-Report (accessed 5 Dec 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 20 May 2013).
- 4 American Youth Soccer Organization. <http://www.ayso.org/AboutAYSO/history.aspx> (accessed 9 Jan 2013).
- 5 National Council of Youth Sports. Report on trends and participation in organized youth sports 2008. <http://www.ncys.org/pdfs/2008/2008-ncysmarket-research-report.pdf> (accessed 10 May 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;21:307–14.

- 8 Outerbridge AR, Micheli LJ. Overuse injuries in the young athlete. *Clin Sports Med* 1995;14:503–16.
- 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;17:201–4.
- 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;34:928–38.
- 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. Physéal injuries in children's and youth sports: reasons for concern? *Br J Sports Med* 2006;40:749–60.
- 14 DiFiori JP. Overuse injury of the physis: a 'growing' problem. *Clin J Sport Med* 2010;20:336–7.
- 15 DiFiori JP. Evaluation of overuse injuries in children and adolescents. *Curr Sports Med Rep* 2010;9:372–8.
- 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;28:480–9.
- 17 Carson WG Jr, Gasser SI. Little leaguer's shoulder. A report of 23 cases. *Am J Sports Med* 1998;26:575–80.
- 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 physéal injury, and ulnar variance in the young gymnast. *Am J Sports Med* 2006;34:840–9.
- 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;46:169–73.
- 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. Washington, DC: Safe Kids Worldwide, 2012. <http://www.safekids.org/assets/docs/safety-basics/sports/2012-sports.pdf> (accessed 9 Jan 2013).
- 23 Comstock D, Collins CL, McLvain NM. Summary report, national high school sports-related injury surveillance study, 2010–2011 school year. <http://www.nationwidechildrens.org/Document/Get/103354> (accessed 10 May 2013).
- 24 Watkins J, Peabody P. Sports injuries in children and adolescents treated at a sports injury clinic. *J Sports Med Phys Fitness* 1996;36:43–8.
- 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;46:206–20.
- 27 Brenner JS. Overuse injuries, overtraining, and burnout in child and adolescent athletes. *Pediatrics* 2007;119:1242–5.
- 28 Bergeron MF. Youth sports in the heat: recovery and scheduling considerations for tournament play. *Sports Med* 2009;39:513–22.
- 29 Aagaard H, Jorgensen U. Injuries in elite volleyball. *Scand J Med Sci Sports* 1996;6:228–32.
- 30 Baxter-Jones A, Maffulli N, Helms P. Low injury rates in elite athletes. *Arch Dis Child* 1993;68:130–2.
- 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;35:1295–303.
- 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;12:80–5.
- 33 Tenforde AS, Sayres LC, McCurdy ML, et al. Overuse injuries in high school runners: lifetime prevalence and prevention strategies. *PM R* 2011;3:125–31.
- 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;46:531–7.
- 35 Lysens RJ, Ostin MS, Vanden Auweele Y, et al. The accident-prone and overuse-prone profiles of the young athlete. *Am J Sports Med* 1989;17:612–19.
- 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;45:880–5.
- 38 Bahr R, Holme I. Risk factors for sports injuries—a methodological approach. *Br J Sports Med* 2003;37:384–92.
- 39 Meeuwisse WH. Assessing causation in sport injury: a multifactorial model. *Clin J Sport Med* 1994;4:166–70.
- 40 Sciascia A, Kibler WB. The pediatric overhead athlete: what is the real problem? *Clin J Sport Med* 2006;16:471–7.
- 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;10:110–16.
- 43 Caine D, Knutzen K, Howe W, et al. A three-year epidemiological study of injuries affecting young female gymnasts. *Phys Ther 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;31:974–80.
- 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;33:1882–91.
- 47 Kucera KL, Marshall SW, Kirkendall DT, et al. Injury history as a risk factor for incident injury in youth soccer. *Br J Sports Med* 2005;39:462–6.
- 48 Caine D, Daly RM, Jolly D, et al. Risk factors for injury in young competitive female gymnasts. *Br J Sports Med* 2006;40:91–2.
- 49 Ramirez M, Brown Schaffer B, Shen H, et al. Injuries to high school football athletes in California. *Am J Sports Med* 2006;34:1147–58.
- 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;38:273–80.
- 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: 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;20:290–8.
- 56 Alexander CJ. Effects of growth rate on the strength of the growth plate-shaft junction. *Skeletal 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;381:212–21.
- 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:1225–31.
- 60 Blimkie CJ, Lefevre J, Beunen GP, et al. Fractures, physical activity, and growth velocity in adolescent Belgian boys. *Med Sci Sports Exerc* 1993;25:801–8.
- 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;12:348–53.
- 62 Niemeyer P, Weinberg A, Schmitt H, et al. Stress fractures in the juvenile skeletal system. *Int J Sports Med* 2006;27:242–9.
- 63 Duggleby T, Kumar S. Epidemiology of juvenile low back pain: a review. *Disabil Rehabil* 1997;19:505–12.
- 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;21:1864–70.
- 65 Maffulli N. Intensive training in young athletes. The orthopaedic surgeon's viewpoint. *Sports Med* 1990;9:229–43.
- 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;44:1186–90.
- 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;11:257–63.
- 68 Falciglia F, Guzzanti V, Di Ciommo V, et al. Physiological knee laxity during pubertal growth. *Bull NYU Hosp Jt Dis* 2009;67:325–9.
- 69 Hawkins D, Metheny J. Overuse injuries in youth sports: biomechanical considerations. *Med Sci Sports Exerc* 2001;33:1701–10.
- 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;187:171–8.
- 71 Shih C, Chang CY, Penn IW, et al. Chronically stressed wrists in adolescent gymnasts: MR imaging appearance. *Radiology* 1995;195:855–9.
- 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;28:1453–8.
- 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;25:700–7.
- 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;37:725–33.
- 75 Thomis M, Claessens AL, Lefevre J, et al. Adolescent growth spurts in female gymnasts. *J Pediatr* 2005;146:239–44.
- 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;38:1487–97.

- 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;40:763–9.
- 78 Ilahe 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;6:307–13.
- 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;22:951–6.
- 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;43:1057–61.
- 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;18:338–43.
- 83 Micheli LJ. Overuse injuries in children's sports: the growth factor. *Orthop Clin North Am* 1983;14:337–60.
- 84 Feldman D, Shrier I, Rossignol M, et al. Adolescent growth is not associated with changes in flexibility. *Clin J Sport Med* 1999;9:24–9.
- 85 Ortega FB, Artero EG, Ruiz JR, et al. Physical fitness levels among European adolescents: the HELENA study. *Br J Sports Med* 2011;45:20–9.
- 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;44:1002–9.
- 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 retorsion. *Am J Sports Med* 2005;33:1716–22.
- 90 Clement DB, Taunton JE, Smart GW. Achilles tendonitis and peritendonitis: etiology and treatment. *Am J Sports Med* 1984;12:179–84.
- 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, Sauer 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 Pee wee 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;146:732–7.
- 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:e112–20.
- 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;172:749–54.
- 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;24:810–18.
- 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;34:108–15.
- 102 Barrow GW, Saha S. Menstrual irregularity and stress fractures in collegiate female distance runners. *Am J Sports Med* 1988;16:209–16.
- 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;157:334–8.
- 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;113:754–9.
- 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;38:1571–7.
- 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;35:711–19.
- 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;39:1867–82.
- 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;39:1464–73.
- 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;34:905–12.
- 110 Rose MS, Emery CA, Meeuwisse WH. Sociodemographic predictors of sports injury in adolescents. *Med Sci Sports Exerc* 2008;40:444–50.
- 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;39:253–7.
- 112 Emery C. Risk factors for injury in child and adolescent sport. *Clin J Sport Med* 2003;13:256–68.
- 113 Loud KJ, Gordon CM, Micheli LJ, et al. Correlates of stress fractures among preadolescent and adolescent girls. *Pediatrics* 2005;115:e399–406.
- 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;33:1803–10.
- 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;30:463–8.
- 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;1:514–17.
- 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;36:686–92.
- 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;39:843–6.
- 121 Cuff S, Loud K, O'Riordan MA. Overuse injuries in high school athletes. *Clin Pediatr* 2010;49:731–6.
- 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: Anderson S, Harris SS. eds. *Care of the young athlete*. 2nd edn. 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, 1982:31–7.
- 128 Nelson MA. Developmental skills and children's sports. *Phys Sports Med* 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 Aicinema 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;5:251–7.
- 133 Hume PA, Hopkins WG, Robinson DM, et al. Predictors of attainment in rhythmic sportive gymnastics. *J Sports Med Phys Fitness* 1994;33:367–77.
- 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:e282–90.
- 136 Abernethy B, Baker J, Côté J. Transfer of pattern recall skills may contribute to the development of sport expertise. *Appl Cognit Psychol* 2005;19:705–18.
- 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;1:231–5.
- 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-Arividu 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;33:734–9.
- 141 Hulkko A, Orava S. Diagnosis and treatment of delayed and non-union stress fractures in athletes. *Ann Chir Gynaecol* 1991;80:177–84.
- 142 Kurd MF, Patel D, Norton R, et al. Nonoperative treatment of symptomatic spondylolysis. *J Spinal Disord Tech* 2007;20:560–4.

- 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, Kobayashi T, Kato K, et al. Diagnosis of radiographically occult lumbar spondylolysis in young athletes by magnetic resonance imaging. *Am J Sports Med* 2013;41:169–76.
- 145 El Rassi G, Takemitsu M, Woratanarat P, et al. Lumbar spondylolysis in pediatric and adolescent soccer players. *Am J Sports Med* 2005;33:1688–94.
- 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 spondylolysis in young athletes. *Curr Sports Med Rep* 2007;6:62–6.
- 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;11:209–13.
- 149 Beutler WJ, Fredrickson BE, Murland A, et al. The natural history of spondylolysis and spondylolisthesis: 45-year follow-up evaluation. *Spine* 2003;28:1027–35.
- 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;13:407–11.
- 152 Goolsby MA, Barrack MT, Nattiv A. A displaced femoral neck stress fracture in an amenorrheic adolescent female runner. *Sports Health* 2012;4:352–6.
- 153 Lehman R, Shah S. Tension-sided femoral neck stress fracture in a skeletally immature patient. *J Bone Joint Surg* 2004;86:1292–5.
- 154 Garcia Mata S, Hidalgo Ovejero A, Martinez Grande M. Transverse stress fracture of the patella in a child. *J Pediatr Orthop B* 1999;8:208–11.
- 155 Iwaya T, Takatori Y. Lateral longitudinal stress fracture of the patella: report of three cases. *J Pediatr Orthop* 1985;5:73–5.
- 156 Shindle MK, Endo Y, Warren RF, et al. Stress fractures about the tibia, foot, and ankle. *J Am Acad Orthop Surg* 2012;20:167–76.
- 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;33:1071–6.
- 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;23:647–50.
- 159 Oestreich AE, Bhojwani N. Stress fractures of ankle and wrist in childhood: nature and frequency. *Pediatr Radiol* 2010;40:1387–9.
- 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;14:381–5.
- 161 Biedert R, Hintermann B. Stress fractures of the medial great toe sesamoids in athletes. *Foot Ankle Int* 2003;24:137–41.
- 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;37:443–50.
- 163 Cahill BR. Stress fracture of the proximal tibial epiphysis: a case report. *Am J Sports Med* 1977;5:186–7.
- 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;9:114–16.
- 165 Laor T, Wall EJ, Vu LP. Physeal widening in the knee due to stress injury in child athletes. *AJR Am J Roentgenol* 2006;186:1260–4.
- 166 Blatnik TR, Briskin S. Bilateral knee pain in a high-level gymnast. *Clin J Sport Med* 2013;23:77–9.
- 167 Green NE, Swiontkowski MF. *Skeletal trauma in children*. 3rd edn. 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;9:23–8.
- 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;44:993–8.
- 170 Wall EJ. Growth plate overuse syndrome of the ankle in athletes. *Med Sci Sport Exerc* 1997;29:299.
- 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;199:1121–8.
- 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;81:1306–10.
- 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;27:844–7.
- 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):58–64.
- 176 Medler RG, McQueen DC. Effort thrombosis in a young wrestler. A case report. *J Bone Joint Surg Am* 1993;75:1071–3.
- 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;41:540–1.
- 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;47:809–20.
- 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;32:107–10.
- 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;43:1287–94.
- 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 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):S60–79.
- 189 Barynina II, Vaitsekhovskii SM. The aftermath of early sports specialization for highly qualified swimmers. *Fitness Sports Rev Int* 1992;27:132–3.
- 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;10:322–40.
- 192 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;69:548–56.
- 193 McCambridge TM, Stricker PR; American Academy of Pediatrics Council on Sports Medicine and Fitness. Strength training by children and adolescents. *Pediatrics* 2008;121:835–40.
- 194 Faigenbaum AD, Myer GD. Resistance training among young athletes: safety, efficacy and injury prevention effects. *Br J Sports Med* 2010;44:56–63.
- 195 Faigenbaum AD, Myer GD. Pediatric resistance training: benefits, concerns, and program design considerations. *Curr Sports Med Rep* 2010;9:161–8.
- 196 Lloyd RS, Faigenbaum AD, Stone MH, et al. Position statement on youth resistance training: the 2014 International Consensus [published online ahead of print]. *Br J Sports Med* 2013. doi: 10.1136/bjsports2013-092952.
- 197 Cahill B, Griffith E. Effect of preseason conditioning on the incidence and severity of high school football knee injuries. *Am J Sports Med* 1978;6:180–4.
- 198 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.
- 199 Heidt RS Jr, Sweeterman LM, Carlonas RL, et al. Avoidance of soccer injuries with preseason conditioning. *Am J Sports Med* 2000;28:659–62.
- 200 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;18:82–8.
- 201 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.
- 202 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.
- 203 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;165:1033–40.
- 204 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.
- 205 Myer GD, Wall EJ. Resistance training in the young athlete. *Oper Tech Sports Med* 2006;14:218–30.
- 206 Faigenbaum A. Resistance training for children and adolescents: are there health outcomes? *Am J Lifestyle Med* 2007;1:190–200.
- 207 Malina RM. Early sport specialization: roots, effectiveness, risks. *Curr Sports Med Rep* 2010;9:364–71.
- 208 Morgan WP, Brown DR. Psychological monitoring of overtraining and staleness. *Br J Sports Med* 1987;21:107–14.