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S.P.O.R.R.T.—A Comprehensive Approach to the Assessment and Non-Operative Management of Overuse Knee Conditions in Youth Athletes

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Abstract

Purpose of Review The evaluation of a young athlete with an overuse injury to the knee involves a comprehensive approach. There are a number of elements to consider including assessments of skeletal maturity (biologic maturation), workload (training load + competition load), sport specialization status, and biomechanics. The type of injury and treatment, as well as future prognosis, may be influenced by these and other factors.

Recent Findings Calculating the percentage of predicted adult height (PPAH) is a valuable tool in assessing overuse injury patterns and diagnoses in youth athletes. Modifiable and non-modifiable overuse injury risk factors require monitoring from clinicians as young athletes mature and develop over time. Training and rehabilitation programs should be adapted to account for these.

Summary In this manuscript, we seek to introduce a novel, comprehensive approach: S.P.O.R.R.T. (**S**keletal Maturity, **P**rior Injury Risk, **O**ne Sport Specialization, **R**ehabilitation, **R**eturn to Play, **T**raining Recommendations) (Fig. 1). Overuse, non-traumatic injuries to the knee in youth athletes will be presented in a case-based and evidence-based model to provide a framework for a comprehensive approach to the assessment and treatment of youth athletes with overuse injuries.

Keywords Knee · Overuse · Sports · Athlete · Non-operative · Youth

Introduction

The knee is often the most common source of injury in youth athletes, and frequently include injuries that are considered overuse (non-traumatic and not related to a single injury). Overuse injuries are prevalent across the board in adolescent athletes and encompass 45.9 to 54% of all sports injuries, with some evidence to support that these injuries are increasing [9]. More specifically, in a previous study of nearly 1200 youth athletes with 822 injuries recorded in a sports medicine clinic, 29.1% of injuries were to the knee, with patellofemoral pain being the most common injury type. Nearly 25% of overuse injuries overall were considered "serious overuse" where they were recommended to stop sports participation for > 1 month by the treating physician [1].

The far majority of overuse injuries of the knee in youth athletes are treated non-surgically, often involving the extensor mechanism, apophyses, or osteochondral regions. The stage of development may influence outcomes, and treatment should involve specific rehabilitation goals, workload modifications and preservation of activity where possible, return to play progressions, and anticipatory guidance. Early identification of potential serious overuse injuries may help limit long absences from sport or perhaps even surgical options. A 3-year longitudinal study of greater than 1200 athletes demonstrated a high recurrence rate of injuries with nearly 70–80% reinjuries during the study period [2•].

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It is felt there may be some youth athletes that are more "load sensitive" and seem to be at a higher risk for recurrent injury despite attempts to return to increase in workloads. It is important to emphasize future adherence to youth sport training recommendations to limit the recurrence of injury.

A S.P.O.R.R.T. approach to evaluating a youth athlete with overuse injury may be a comprehensive way to evaluate, manage, and reduce reinjury, particularly with overuse injuries to the knee (Fig. 1).

Skeletal Maturity/Peak Height Velocity

When evaluating and treating adolescent athletes, it is imperative to recognize their specific stage of development, as it can be crucial in identifying pathology and formulating an appropriate rehabilitation program, subsequent return to play, and future anticipatory guidance [3••]. Young athletes are more vulnerable to overuse and growth plate injuries secondary to the effects of the adolescent growth spurt [4]. On average, this growth spurt generally takes place at 9 to 10 years of age in girls and 11 to 12 years of age in boys, although this can vary considerably [5]. During this period of accelerated growth, adolescents experience a rapid increase in height followed by mass [6]. Calculating the percentage of predicted adult height (PPAH) is a valuable tool in the assessment and treatment of youth athlete injuries and can be used to assess their risk of injuries as well. Using the Khamis-Roche method, which requires the athlete's age, height, weight, and the heights of the child's biological parents, one can predict adult stature in the absence of skeletal age [7]. This method can also be further utilized to estimate when the athletes are entering and exiting the adolescent growth spurt, with take-off approximately at 85% PPAH, peak height velocity (PHV) around 91%, and the end of deceleration phase at about 96% [8, 9]. This estimated range of PPAH between 85 and 96% was shown to accurately identify 91% of athletes, though, more recent data suggest this range to be closer to 87–95%, which coincides with the transition from pre-PHV to circa-PHV and the instance when PHV for leg length takes place [10, 11••].

Anterior knee pain is one of the most frequent complaints in the young athlete, with apophyseal injuries occurring more often in early adolescence and patellofemoral pain syndrome becoming a more common cause later in adolescence [12]. Studies have shown that skeletally immature athletes in a phase of rapid growth are more susceptible and less resistant to tensile, shear, and compressive forces than that of both mature bone and prepubescent bone. Coupling this with repetitive loading and stress leaves this group of adolescent athletes at great risk of injury [13••]. Prior research has demonstrated that there is a direct correlation between athletes experiencing larger changes in stature and leg length and the occurrence pattern of growth-related injuries [14]. Data suggests that this injury incidence pattern occurs from distal to proximal segments. For example, the peak incidence of Osgood-Schlatter disease occurs around the peak of the adolescent growth spurt (88% PPAH; pre-PHV) [11••]. This also applies to other overuse injuries including Sinding-Larsen-Johansson syndrome and osteochondritis dissecans, whereas cases of spondylosis of the lower back are more prevalent around the growth spurt deceleration point (96% PPAH) [3••]. Data shows that the large majority of muscle injuries such as quadriceps, hamstring, and adductor occur post-PHV [11••]. Additionally, knee joint and ligament injuries are also overwhelmingly prevalent post-PHV [11••].

Furthermore, calculating and using PPAH as an identification tool thus becomes invaluable in the workup of suspected overuse injury in youth athletes. It is essential to identify where a youth athlete lies on the growth curve and to make appropriate modifications to their training load and rehabilitation when injured. This load needs to be structured relative to skeletal maturity and the athlete's growth phase to heighten their peak performance and reduce injury [15]. PPAH > 96% and post-PHV are associated with low injury risk, PPAH < 85% and pre-PHV are associated with

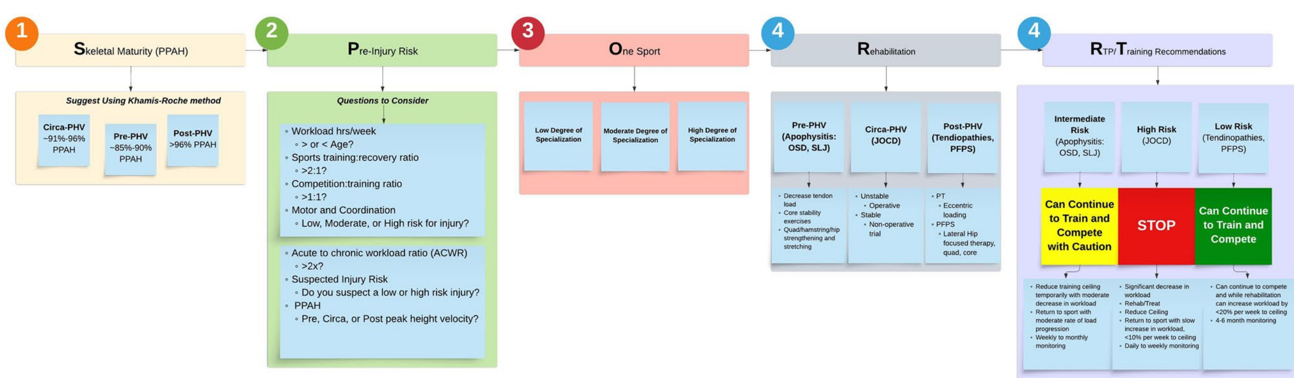

Fig. 1 S.P.O.R.R.T. approach

moderate injury risk, and PPAH 85–96% and circa-PHV are associated with high injury risk [3••].

Prior Injury Risk

Both modifiable and non-modifiable risk factors have been identified for overuse injuries. Modifiable risk factors may include training volume/loads/history, flexibility, strength, aerobic fitness, biomechanics, recovery time, preparedness, and sport specialization; non-modifiable risk factors may include timing of accelerated growth spurts, biological maturity, chronological age, body size, and history of previous injury [3••, 16–18]. Van Der Sluis et al. conducted a study examining adolescent growth spurts and found that players who mature later have a higher incidence of overuse injuries when compared to players who mature earlier. This was found to be true both in the year before PHV and the year of PHV. Additionally, players aged between 13.5 and 14.5 have been shown to be at an increased risk of injury [3••, 15].

A history of previous injury was found to be the strongest predictor of sustaining future injuries, as it can predispose young athletes to repetitive stress injuries [16]. A study identifying risk factors for lower-extremity injury among high school cross-country runners found a significant link between previous injury and risk of future injury. For females, an injury during the summer prior to the season and a quadriceps angle of ≥ 20° were the most important predictors of injury. For males, a history of multiple running injuries and a quadriceps angle of ≥ 20° were the most important predictors of injury [19]. These injuries can be categorized as high versus low risk. Per the American Medical Society of Sports Medicine, high-risk overuse injuries often require surgery, such as fifth proximal diaphyseal stress fractures, navicular bone stress injuries, etc. [3••, 13••]. Serious overuse injuries are also categorized as injuries that require cessation of sport for 1 month or longer, including bone stress injuries and osteochondral injuries [1, 3••]. Low-risk injuries may not require sports cessation and instead require modification of workloads during rehabilitation and then staged progressions in training load to gradually work back toward their potential capacity. These low-risk injuries include muscular injuries, apophysitis, and anterior knee pain syndromes [3••].

Measurable modifiable overuse injury risk factors include workload, motor and coordination, sports training ratio, competition-to-training ratio, and acute-to-chronic workload ratio (ACWR) [3••]. Workload refers to the total volume and intensity of physical activity performed by an athlete over a period of time and includes training sessions as well as competitions. Workload is considered low or moderate risk if it is limited to fewer hours per week than the child's age. Workload is considered high risk when it is more hours per week than the child's age. Children with a high risk workload are more likely to develop a serious overuse injury. [3••] Deficits in motor and coordination are also likely to increase the risk of overuse injuries and may be more prevalent in female, specialized athletes [3••, 20•].

Sports training ratio refers to the ratio of weekly hours in organized sports to weekly hours in unorganized free play. Youth athletes that focus extensively on skill-based training (including sport-specific techniques) and neglect their physical conditioning may be more susceptible to overuse injuries. Low-risk athletes have a sports training ratio of < 2:1, while moderate and high-risk athletes have a sports training ratio of > 2:1 [3••]. Competition-to-training ratio is defined as the proportion of time an athlete spends in competition compared to training. Typically, athletes who participate in an excessive number of competitions in comparison to their training time are at an increased risk of overuse injuries. It has been suggested that a competition-to-training ratio of < 1:3 is considered low risk, a competition-to-training ratio of < 1:1 is considered moderate risk, and a competition-to-training ratio of > 1:1 is considered high risk [3••].

ACWR is a measure that compares an athlete's recent (or acute) workload to their previous (or chronic) workload that took place over a longer period of time. Sudden increases or significant changes in workload will result in high acute-to-chronic workload ratios, which can increase an athlete's risk of overuse injuries. It is suggested that an ACWR > 0.8 and < 1.3 is low risk, ACWR > 1.5 is moderate risk, and ACWR > 2.0 is high risk [3••]. The prompts outlined in Table 1 can be used to calculate these modifiable overuse injury risk factors. Certain health factors have also been shown to increase injury risk, including academic and emotional stress, anxiety, stress-related personality traits, and lack of sleep [3••, 21–24]. It has been suggested that adolescents who sleep less than 8 h per night are 1.7 times more likely to experience an injury [3••, 24].

One Sport (Sport Specialization)

The term "sport specialization" was first defined as year-round (> 8 months) dedicated participation in one main sport at the exclusion of engaging in other sports or activities [25]. Additionally, the concept of "early sport specialization," focusing on one main sport prior to age 12, was first introduced in the AOSSM position statement in 2016 [26]. Using the 3-question survey created by Jayanthi et al., an athlete's degree of sport specialization is categorized as low (0 to 1 points), moderate (2 points), and high (3 points) based on responses to these questions [1]. In the same study, highly specialized athletes were associated with the greatest risk for injury and serious overuse injury, independent of age,

Table 1 Prompts to calculate modifiable overuse injury risk factors in athletes

Prompts	Low Risk of Injury	Moderate Risk of Injury	High Risk of Injury
During an average healthy 4-week period, the number of hours I play organized sports (training, practicing, competition, conditioning, etc.) per week is:	Workload hrs/week < age	Workload hrs/week < age	Workload hrs/week > age
During an average healthy 4-week period, the number of hours I play sports just for fun (for example, playing basketball with friends at recess or after school) per week is:	Sports training ratio <2:1	Sports training ratio >2:1	Sports training ratio >2:1
Over the last 4 weeks, the number of hours related to competitions compared to training was:	Competition to training ratio <1:3	Competition to training ratio <1:1	Competition to training ratio >1:1
The average number of workload hours over the past 1 week compared to over the previous 4 weeks was:	ACWR >0.8 and <1:3	ACWR >1.5	ACWR >2.0

and weekly training hours, when compared to athletes in the other two categories. [1].

Additionally, sport specialization has been thought to result in a poor development of fundamental movement skills in youth athletes. Generalized physical activity promotes the development of motor skills through exposure to various movement patterns [27]. Sport specialization, especially in the case of the early sport specialization, may not provide athletes with the same wide exposure to movement patterns, preventing the motor-development and motor-coordination processes obtained during adolescence [20•]. A recent study illustrated that altered lower extremity coordination while landing when performing drop-vertical-jump in the sport-specialized group may lead to unstable landings, ineffective force absorption techniques, and/or increased contact forces, resulting in greater lower extremity injury risk in female athletes who participate in one main sport early on their careers [20•].

Lastly, the psychosocial effects of youth sport specialization should not be forgotten. An appropriate amount of physical activity and sport participation among children and adolescents has been typically associated with improved psychosocial well-being [28]. However, mental health and function could be negatively affected among those youth athletes who specialized early in their career secondary to numerous factors, including social isolation, poor academic performance, increased anxiety, greater stress, inadequate sleep, decreased family time, and burnout [13••, 29–33].

Rehabilitation/Return to Play

Rehabilitation of anterior knee pain needs to be individualized (Fig. 2). However, in general, the focus should be on hip and thigh muscle strengthening, both of which have been reported to significantly decrease pain and improve function in the short-, medium-, and long-term [34•]. In order to determine which muscle groups need to be preferentially treated, the strength of the bilateral quadriceps muscles, hamstring muscles, and hip muscles (including the hip abductor, adductor, flexor, extensor, internal rotator, and external rotator muscles) should be tested before initiating the rehabilitation program, using an isokinetic machine or handheld dynamometer to evaluate for side-to-side asymmetry [35••]. For instance, for those who have relative quadriceps weakness, quadriceps strengthening should be their focus with knee extension via open-kinetic-chain with a variable moment arm from 90 to 45° and closed-kinetic-chain from 0 to 45° [35••], as these values were associated with lower patellofemoral joint stress [36]. The safe return to play process should be viewed as a continuum with first restoration to preinjury activity via cessation of sport, rehabilitation, modification of workloads, or sport participation with their new lowered ceiling, followed by resumption of preinjury sport, and finally, a return to pre-injury level performance [37]. Prior to sport participation, athletes are recommended to achieve at least 90% limb symmetry index (LSI) for knee and hip musculature [38]. Additionally,

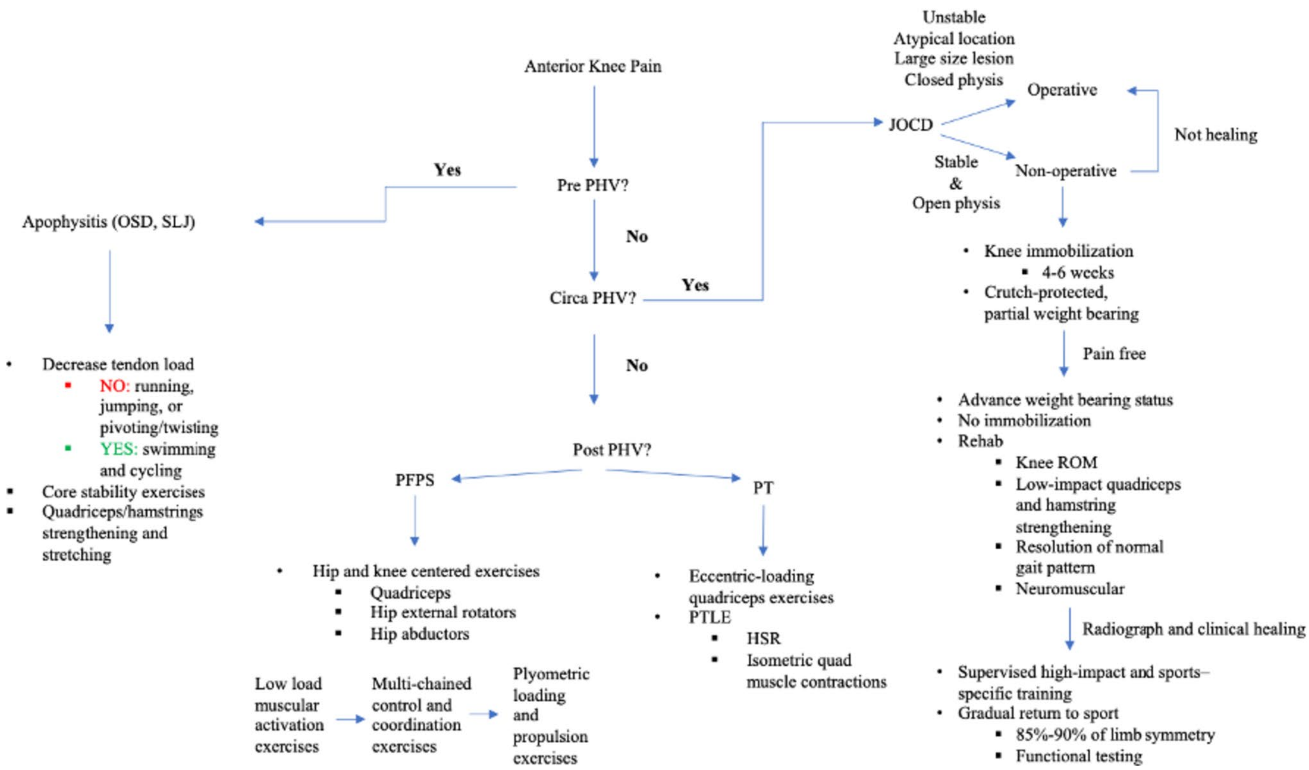

Fig. 2 Rehabilitation of anterior knee pain (based on stages of development where more likely to see each condition)

restoration of the functional performance of the injured knee is critical to evaluate readiness for sport participation [39]. This can be measured in single-limb hop tests [40], 10-s tuck jump assessment [41], drop vertical jump [42], and the Vail Sport Test [43], all of which have been reported to be valid and reliable functional performance measures.

Training Recommendations

Individualized adjustments of training load for sport-specialized athletes have been proposed as a method to safely progress these athletes to peak performance and maintain their ability to specialize [44, 45••]. These individualized training models have the potential to safely prioritize performance in specialized youth athletes and adapt with these athletes as they progress through vulnerable maturational periods and injury [3••]. Training load has been shown to play an important role in capacity, performance, and injury [13••]. Effective training load progressions can improve performance and capacity and develop resilient athletes [1, 13••].

Three classifications of youth athletes can be considered to help determine and prescribe appropriate load progressions: load-tolerant (low risk), load-naïve (moderate risk), and load-sensitive (high risk) [45••]. Athletes who are load tolerant have a high capacity to handle more demanding training loads without experiencing overuse injury or other significant negative effects. These individuals often adapt well to increased training demands and have efficient movement patterns with well-conditioned tissues and muscles. They are skeletally mature and/or have experienced more intense training loads. Load-tolerant athletes can safely tolerate increasing loads with continual performance benefits; thus, can often train at a higher age-predicted level to improve from their current capacity more rapidly to their potential capacity [45••]. Current capacity can be thought of as the athlete's floor; potential capacity can be thought of as the athlete's ceiling. A load-tolerant athlete typically has a positive response to continued loading as they move through pubertal growth and skeletal maturity. These athletes can continue to work toward their optimum workload, increasing their workload by < 20% each week until peak performance is achieved [3••, 45••].

Load-naive athletes have a lower tolerance for training loads and include beginners, individuals who are relatively unfit, and those who have been inactive because of injury or other reasons. These individuals are more susceptible to overuse injuries as their musculoskeletal systems, muscles, and tissues are not as familiar with heavy training loads. They are skeletally immature and/or have not experienced more intense training loads. It is recommended that these athletes limit the total number of weekly training hours according to their age [3••, 45••]. As a result, they may benefit from smaller increases in load and temporary capacity lowering in order to decrease overuse injury risk [45••]. When returning to sport, these athletes should focus on moderate increases in workload by 10–15% per week to achieve their lowered ceiling [3••, 45••].

Athletes who are load-sensitive require a balance between training load and their body's ability to tolerate it. These athletes are either skeletally immature or skeletally mature and/or have suffered injury or recurrent injury related to training. They require a more cautious and individualized approach to training, with an emphasis on modifying the training load as needed in a stepwise fashion to prevent overuse injuries [45••]. These athletes benefit from significant decreases in workload and reductions in their ceiling. They must focus on rehabilitation and increase the frequency of serial monitoring to daily or weekly. When returning to sport, these athletes should focus on mild increases in workload by < 10% per week to achieve their lowered ceiling [3••, 45••]. It is possible for athletes to have success with specialized training through the use of a prescribed training load program that accounts for factors that impact the workload-injury relationship as well as injury risk factors [3••]. Table 2 outlines an approach for assessing youth athlete injury risk factors and creating a corresponding workload progression training prescription.

Case #1

Eleven-year-old female basketball player who plays for her middle school basketball team presents to your office with several months of intermittent anterior infrapatellar knee pain. The pain is worse with running and jumping and improves with rest. (Refer to Table 3., *Case #1)*

Apophyses are normal bony outgrowths that arise from separate ossification centers which later fuse. The apophysis is a site of tendon or ligament attachment, differing from the epiphysis, which refers to the distal or end portion of a long bone. Apophysitis is inflammation of an apophysis usually secondary to overuse and chronic repetitive microtrauma [46], most frequently found in skeletally immature athletes [47]. Apophysitis of the knee can be differentiated by anatomical location. Apophysitis at the insertion of the patellar tendon on the tibial tubercle is known as Osgood-Schlatter's disease (OSD). When it occurs at the inferior pole of the patella, where the patellar tendon originates, it is called Sinding Larsen-Johansson (SLJ).

Symptoms of OSD usually occur during periods of rapid growth in adolescents who take part in regular sports [48]. OSD is more commonly seen in male athletes, specifically in those who participate in sports that include running and jumping. Like OSD, athletes with SLJ commonly present with a gradual onset of anterior knee pain, localized to the distal or inferior pole of the patella, and the proximal attachment of the patellar tendon.

OSD can be commonly treated conservatively [49, 50] as symptoms typically subside spontaneously when the affected area completes its growth, around Risser Stage 1 [51]. It is recommended that high-impact activities should be avoided while athletes are symptomatic [52]. On the other hand, athletes can participate in low-impact activities such as swimming and cycling [48]. Core stability and quadriceps/hamstring strengthening and stretching exercises are considered essential [48]. However, there is a paucity of data on the effectiveness of specific exercises compared to sham or usual care treatment [53]. Rathleff et al. reported high rates of successful outcomes among OSD patients (80% at 12 weeks and 90% after 12 months), with 16% having returned to sport after 12 weeks, and 67% after 6 months [54]. As in OSD, SLJ is usually a self-limiting condition without any significant long-term complications. The disorder generally resolves with skeletal maturity and the treatment is normally conservative.

Current literature is lacking when it comes to evidence-based recommendations for return to play. As such, we typically recommend youth athletes perform pain-free single leg squats and single-leg hops for distance, followed by specific sport on-field progression without recurrence or worsening of pain before fully returning to their sports.

Case #2

Fourteen-year-old male tennis player who plays for a club team presents to your office with several weeks of poorly localized activity-related knee pain, aggravated by bearing weight. (Refer to Table 3., *Case #2)*

Osteochondritis dissecans (OCD) is an acquired condition of the joint, resulting in an injury to the articular surface and the subchondral bone [55•]. OCD can be classified into two types [56] where the juvenile form of the disease occurs in those whose growth plates are still open [57]. The highest incidence is seen in patients aged between 10 and 20 years old [58], and males have a higher incidence of OCD as much as 4 times when compared to females [59]. Although OCD of the knee can be seen in different parts of the joint (i.e. the lateral femoral condyle, patella, or tibial plateau), the lateral aspect of the medial femoral condyle is the most frequent anatomical location [60]. While the precise cause of OCD is poorly understood, the etiology seems to be multifactorial [61]. Patients with OCD of the knee may present with pain with weight-bearing, limping, knee swelling, or locking symptoms.

The management of juvenile osteochondritis dissecans (JOCD) remains controversial; however, non-operative management should be the gold standard for stable disease in skeletally immature young athletes. This includes

Table 2 Youth athlete injury risk factor assessment and workload progression training prescriptions, ACWR, acute:chronic workload ratio; PHV, peak height velocity; PPAH, percentage of predicted adult height

Low Risk, Load Tolerant Athlete	Prescription: Train and Compete to Optimum Loads
Modifiable Risk Factor Assessment: ☐ Low degree of sports specialization ☐ Workload hrs/week < age ☐ Minimal deficits in motor and coordination ☐ Sports training ratio <2:1 ☐ Competition to training ratio <1:3 ☐ ACWR >0.8 and <1:3 ☐ Low degree of academic/emotional stress and anxiety ☐ Sleep >/=8 hrs/night Non-Modifiable Risk Factor Assessment: ☐ No history of overuse injury ☐ Post-PHV ☐ PPAH >96% ☐ Age not between 13.5-14.5	Plan of Action: ☐ Continue training and competing toward optimum workload ☐ Increase workload by <20% per week to achieve potential capacity (peak performance) ☐ Serial Monitoring every 4-6 months
Moderate Risk, Load Naive Athlete	**Prescription: Train and Compete with Caution**
Modifiable Risk Factor Assessment: ☐ Moderate degree of sports specialization ☐ Workload hrs/week < age ☐ Mild-moderate deficits in motor and coordination ☐ Sports training ratio >2:1 ☐ Competition to training ratio <1:1 ☐ ACWR >1.5 ☐ Moderate degree of academic/emotional stress and anxiety ☐ Sleep <8 hrs/night Non-Modifiable Risk Factor Assessment: ☐ History of low-risk overuse injury ☐ Pre-PHV ☐ PPAH <85% ☐ Age between 13.5-14.5	Plan of Action: ☐ Increase frequency of serial monitoring to weekly to monthly ☐ Moderate decrease in workload ☐ Temporarily reduce current/potential capacity ☐ Return to sport with moderate increase in workload by 10-15% per week to achieve potential capacity ☐ Discuss adaptation of plan with your sports medicine provider if experiencing persistent pain anywhere for 2 weeks or for 1 week in high-risk area (including low back, shoulder, elbow) ☐ Work to improve stress reduction/sleep habits
High Risk, Load Sensitive Athlete	**Prescription: Reduce Training and Competition**
Modifiable Risk Factor Assessment: ☐ High degree of sports specialization (>8 months of dedicated participation in one sport) ☐ Workload hrs/week > age ☐ Severe deficits in motor and coordination ☐ Sports training ratio >2:1 ☐ Competition to training ratio >1:1 ☐ ACWR >2.0 ☐ High degree of academic/emotional stress and anxiety ☐ Sleep <8 hrs/night Non-Modifiable Risk Factor Assessment: ☐ History of high-risk overuse injury ☐ Circa-PHV ☐ PPAH 85-96% ☐ Age between 13.5-14.5	Plan of Action: ☐ Discuss adaptation of plan with your sports medicine provider immediately; Increase frequency of serial monitoring to daily to weekly ☐ Significant decrease in workload ☐ Reduce current/potential capacity ☐ Focus on SPORRT rehabilitation and treatment model ☐ Return to sport with slow increase in workload by <10% per week to achieve potential capacity ☐ Work to improve stress reduction/sleep habits

Table 3 Case-based approach using S.P.O.R.R.T.

	Case Based Approach Using S.P.O.R.R.T.					
		Skeletal Maturity (Khamis-Roche method)	Prior Injury Risk (Refer to tables 1 and 2)	One Sport Specialization (Refer to 3 question survey Jayanthi et al.)	Rehabilitation	RTP/Training Recommendations (Refer to Figure 1, part 4)
Case #1	*11 y/o basketball player w/ several months of intermittent knee pain distal to kneecap. The pain is worse with running and jumping and improved with rest.*	PPAH 88%= Pre-PHV	Load Naive	Moderate Degree of Specialization	◦ Decrease tendon load ◦ Core stability exercises ◦ Quad/hamstring/hip strengthening and stretching	Intermediate Risk
Case #2	*14 y/o tennis player presents to your office with several weeks of poorly localized activity-related knee pain, aggravated by bearing weight.*	PPPAH 92%=Circa-PHV	Load Sensitive	High Degree of Specialization	◦ Unstable ◦ Operative ◦ Stable ◦ Non-operative trial	High Risk
Case #3	*16 y/o soccer player presents with dull and achy pain surrounding and behind both of her kneecaps that has been worsening for the past 2 months. The pain worsens with repetitive movements such as running, kicking, and quickly changing directions.*	PPAH 98%=Post-PHV	Load Tolerant	Low Degree of Specialization	◦ PT ◦ Eccentric loading ◦ PFPS ◦ Lateral Hip focused therapy, quad, core	Low Risk

immobilization (casting, bracing, splinting, and unloader brace), limited weight-bearing, and activity restriction [55•] as about 50 to 67% of the lesions heal after 6 to 12 months of conservative management [62–66]. Three-phase approach has been described by Kocher et al. [67] The first phase consists of knee immobilization for between 4 and 6 weeks with crutch-protected, partial weight-bearing status [67]. Prior to advancing to the second phase, the patient should be pain-free and repeat X-rays should be obtained [67]. During the second phase (weeks 6–12), weight-bearing status is advanced without immobilization restrictions [67]. While participation in sports and high-impact activities is still restricted, a rehabilitation protocol is introduced, focusing on knee range of motion and low-impact quadriceps and hamstring strengthening exercises [67] as well as restoration of normal gait pattern, resolution of isolated muscle strength deficits, and improvement of neuromuscular control [39]. To recover isolated strength deficits and dynamic limb control, both open and closed kinetic chain exercises should be included [39]. Once radiographic and clinical signs of healing are noted at 3 to 4 months following the initial diagnosis, the third phase can be initiated, including participation in supervised impact and sports-specific training with a gradual return to sport [67].

Case #3

Sixteen-year-old female soccer player who plays for her high school soccer team presents to your office with dull and achy pain surrounding the retropatellar region that has been worsening for the past 2 months. The pain worsens with repetitive movements such as running, kicking, and quickly changing directions. (Refer to Table 3.*, Case #3)*

Patellofemoral pain syndrome (PFPS) is a condition characterized by anterior knee pain, specifically around or behind the patella, and is typically experienced under loading and compressive forces. The pain is often described as dull and achy and is aggravated by repetitive knee bending or high-impact movements with significant quadriceps demand [68, 69]. Patellofemoral pain accounts for 25 to 40% of all knee complaints in sports medicine clinics and can persist for years, sometimes causing decreased sports participation [69, 70]. PFPS is caused by abnormal tracking of the patella in the trochlear groove, typically instigated by lower extremity malalignment, muscular imbalance or insufficiency, decreased flexibility, patellar hypermobility, unsound running mechanics, and overactivity [71•].

Exercise therapy, targeting both hip and knee-centered exercises, has been recommended to decrease pain and improve function for patients with PFPS [68]. Increased concentric and eccentric strength of the hip rotator and abductor muscles leads to improved femoral positioning on the tibia during dynamic activities, resulting in reduced patellofemoral stress [71•]. Mellinger and Neurohr described a three-phase protocol with initial exercise prescription including low-load muscular activation exercises (i.e., side plank, quadruped fire hydrants, lateral step down, and three-way straight leg raise), followed by multi-chained control and coordination exercises (i.e., single leg squats, split squat, step up plus, and three-way slider lunges), and finally plyometric loading and propulsion exercises (i.e., double leg squat jumps, double leg box jumps up/down, single leg hop downs, and single leg forward hops) [71•].

Patellar tendinopathy (PT) is characterized by pain at the attachment of the patellar tendon at the inferior pole of the patella. Athletes with PT are typically only symptomatic in high-energy activities, such as the repetitive jumping and quadriceps loading required for volleyball, basketball, tennis, and football [71•]. PT begins as a non-inflammatory process in response to an overloaded tendon, which leads to the development of a thickened tendon. Continued overload then leads to tendon disrepair, increased thickening, and ultimately a more disorganized tendon matrix [72, 73].

Eccentric-loading quadriceps exercises have been recommended for the management of PT for many years [74–76]. A 2019 meta-analysis by Andriolo et al. illustrated the effectiveness of eccentric exercises in the short term [77]. More recently, however, a progressive tendon loading exercise (PTLE) through heavy slow resistance (HSR) training or isometric quadriceps muscle contractions has gained popularity in being incorporated into rehabilitation regimens along with eccentric exercises. A randomized control study by Breda et al., comparing eccentric exercise and a 4-stage progressive tendon loading exercise regimen ("isometric, isotonic, energy storage explosive, and sport-specific exercise") for the treatment of PT, demonstrated that the latter approach resulted in better subjective functional outcomes at 6 months [78•]. The goals of rehabilitative management of PT should include initial pain control followed by eccentric exercises or PTLE to gradually improve load tolerance of the injured tendon [79].

Both PFPS and PT most frequently occur in athletes who are skeletally mature (PPAH > 96% and post-PHV). Due to the lower-risk nature of these conditions, athletes can continue to train and compete while completing rehabilitation, can increase their workload by < 20% per week to work towards achieving their ceiling, and can be monitored less frequently (every 4–6 months).

Conclusion

Approximately 57.7% of United States youth participate in organized sports each year. [80] It is estimated that about half of all youth athletes will experience knee pain annually and approximately half of all knee injuries are due to overuse etiologies [81].

We have introduced a comprehensive approach for the evaluation of overuse injuries in youth athletes that focuses on elements that include skeletal maturity (biologic maturation), workload (training load + competition load), injury risk, sport specialization status, and biomechanics. Evaluating athletes in this manner allows the provider to assess, diagnose, and prescribe the most effective rehabilitation program and return-to-play guidance more accurately.

We also discussed the importance of modifiable and non-modifiable overuse injury risk factors as young athletes mature and develop over time. Training programs should be designed to account for anthropometric (height and weight) and physical characteristics (range of motion and strength) while also focusing on improving flexibility, muscle strength, aerobic fitness, and balance deficits, which have been shown to protect against injury in this population and improve performance [3••, 16, 82, 83]. Training programs should also focus on being well-rounded with the inclusion of strength, conditioning, and sport-specific skill training [3••]. Additionally, injury prevention strategies for youth and adolescent athletes stress the importance of limiting time spent in training and competition with some scheduled rest time to promote proper recovery [16]. Another intervention that has been shown to decrease the risk of injury is integrated neuromuscular training, which targets coordination deficits [3••, 84]. The complexity of factors at play regarding youth overuse knee injuries also emphasizes the importance of individualized monitoring and training programs that center around training load adjustments [45••].

Declarations

Conflict of Interest Neeru Jayanthi, Jacob Davis, Bridget Doyle, and Haruki Ishii declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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