Case Report

Specialized Neuromuscular Training to Improve Neuromuscular Function and Biomechanics in a Patient With Quiescent Juvenile Rheumatoid Arthritis

Background and Purpose. The purpose of this case report is to describe a novel multidisciplinary approach for evaluating and preparing a patient with quiescent juvenile rheumatoid arthritis (JRA) for safe sports participation. Case Description. The patient was a 10-year-old girl with a history of bilateral knee arthritis who desired to participate in soccer and basketball. Range of motion and manual muscle testing of the lower extremity were within normal limits. Neuromuscular testing included kinematic and kinetic testing, isokinetic assessment, and postural stability testing. The patient's gait was near normal; however, she had narrowed step width and increased knee flexion at heel-strike. Landing analysis during a box drop vertical jump task showed increased and imbalanced (right versus left lower extremity) peak impact forces. The testing was followed by specialized neuromuscular training (SNT). Outcomes. Following SNT, heel-strike and step width were within normal limits, peak impact forces on the box drop test decreased by 31%, imbalance decreased by 46%, and vertical jump increased 15%. The isokinetic strength ratio between knee flexors and extensors and the overall balance measures were within normal limits and equal bilaterally. Discussion. Patients with quiescent JRA may have abnormal biomechanics, which could place them at increased risk for injury or future articular cartilage damage. Specialized neuromuscular training may have helped to decrease the patient's risk for future injury or disease progression. [Myer GD, Brunner HI, Melson PG, et al. Specialized neuromuscular training to improve neuromuscular function and biomechanics in a patient with quiescent rheumatoid arthritis. *Phys Ther.* 2005;85:791–802.]

Key Words: *Biomechanics, Gait, Injury prevention, Juvenile rheumatoid arthritis, Neuromuscular training, Sport participation.*

Gregory D Myer, Hermine I Brunner, Paula G Melson, Mark V Paterno, Kevin R Ford, Timothy E Hewett

This case report describes a multidisciplinary approach for evaluating and preparing a patient with quiescent juvenile rheumatoid arthritis for safe sports participation.

Juvenile rheumatoid arthritis (JRA) is a childhood disease characterized by chronic, recurrent inflammation of joints. Some types of JRA can involve systemic inflammation. Classifications of JRA include systemic, polyarticular (5 or more joints involved), and pauciarticular (4 or fewer joints involved).[1] The current estimated prevalence of active and inactive cases of JRA in the United States is between 30,000 and 50,000.[2] Although JRA rarely is a life-threatening condition, it can affect a person's growth, development, and quality of life. Historically, patients with JRA have been managed with medication and exercise. Recent evidence suggests that joint damage in people with JRA may be more related to exercise than to aggressive drug therapy in the early stages[3]; however, this link has not yet been made for exercise management.

Articular effusion and synovial hypertrophy are hallmarks of the disease.[4] The mechanical effects of these abnormalities, compounded by the potentially erosive effects of the inflammatory process, can lead to transient or long-term musculoskeletal defects.[5] Involved joints are often held in a position of comfort, usually flexion. Delayed neuromuscular development, muscular weakness, ligamentous laxity, and generalized or localized growth disturbances can all be factors that contribute to musculoskeletal changes.[6] The condition usually requires long-term medical treatment and results in at least some restrictions of physical activity, which depend on the type and severity of the disease. Children with JRA usually self-limit their physical activity according to symptoms, but caregivers also may modify activity or restrict high-impact physical activity. Patients may remain involved in sports activities or may have to discontinue participation temporarily or permanently. Children whose disease does not cause substantial long-term deficits often desire to return to some level of recreational or competitive sports if possible.[4] According to the World Health Organization, a limitation in activities or a restriction in activity participation with peers is included in the definition of disability.[7] Clinical caregivers, therefore, should aim interventions beyond preserving basic activities of daily living. This is especially important because improved medical therapies are leading to improved physical outcomes and more active lifestyles in children with JRA.[5]

The American College of Rheumatology[8] recommends muscle strengthening (exercises to improve force-generating capacity of the muscle) and aerobic conditioning programs for management of rheumatoid arthritis (RA). De Jong and colleagues[9,10] evaluated the effects of long-term intensive exercise in adults with RA. They determined that patients who participated in intensive exercise training, including aerobic, strengthening, and impact sport activities showed greater improvements in

GD Myer, MS, CSCS, is Sports Biomechanist, Sports Medicine Biodynamics Center and Human Performance Laboratory, Cincinnati Children's Hospital Medical Center, 3333 Burnet Ave, MLC 10001, Cincinnati, OH 45229 (USA) (greg.myer@cchmc.org). Address all correspondence to Mr Myer.

HI Brunner, MD, MSc, FAAP, FACR, is Assistant Professor of Pediatrics, Cincinnati Children's Hospital Medical Center.

PG Melson, PT, MMSc, is Rehab Coordinator for Rheumatology, Cincinnati Children's Hospital Medical Center.

MV Paterno, PT, MS, SCS, ATC, is Coordinator of Orthopaedic and Sports Physical Therapy, Sports Medicine Biodynamics Center and Division of Occupational Therapy and Physical Therapy, Cincinnati Children's Hospital Medical Center.

KR Ford, MS, is Research Biomechanist, Sports Medicine Biodynamics Center and Human Performance Laboratory, Cincinnati Children's Hospital Medical Center.

TE Hewett, PhD, is Director, Sports Medicine Biodynamics Center and Human Performance Laboratory, Cincinnati Children's Hospital Medical Center, and University of Cincinnati College of Medicine, Pediatrics, Orthopaedic Surgery and Rehabilitation Sciences.

All authors provided concept/idea/project design and writing. Mr Myer, Mr Paterno, and Mr Ford provided data collection, and Mr Ford provided data analysis. Mr Myer, Ms Melson, Dr Brunner, and Mr Paterno provided project management. Ms Melson and Dr Brunner provided the patient. Dr Hewett provided facilities/equipment, institutional liaisons, and consultation (including review of manuscript before submission).

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functional ability and patient satisfaction than the patients who received standard care.[9,10] Radiographs did not show increased damage in large joints of patients who did intensive exercise except in patients with high baseline damage.[10] Similar studies with children are not available, but an extrapolation of the data for adults suggests that exercise may be of benefit in patients with JRA and might not increase the symptoms. However, the long-term risks for articular damage, especially in those patients who participate in high-loading activities, have yet to be determined.[11] No studies have evaluated patients with JRA to determine the magnitude of forces in involved joints during joint loading activities. The lack of research in this area limits clinicians from providing recommendations for high-level activity. Furthermore, the efficacy of neuromuscular training targeted to address any measured deficiencies in children with JRA has not been reported in the literature.

The purposes of this case report are: (1) to quantify gait, motion patterns, strength, balance, joint reaction forces, and joint symmetry of a patient with quiescent JRA disease and (2) to describe a novel multidisciplinary approach to training a child with JRA to prepare her for safe entry into sport competition.

Case Description

Patient Description

The patient was diagnosed with pauciarticular JRA at age 5 years. She had diffuse bilateral knee effusions and stiffness after inactivity. The standard of care in our institution was a multidisciplinary approach including medical management from the rheumatology and physical therapy divisions. Medical management consisted of nonsteroidal anti-inflammatory medications (NSAIDs) and bilateral intra-articular corticosteroid injections. Physical therapy was initiated at that time with a general lower-extremity musculoskeletal evaluation. A home exercise program (HEP) addressed loss of motion and decreased strength. Periodic physical therapy interventions continued after the HEP began to provide patient and family education regarding joint protection, suggested activity modifications, and modifications of the HEP as indicated by changes in disease and functional status. During periods of increased joint inflammation, the home program included exercises to preserve the patient's range of motion (ROM) and strength. The program progressed to include low-impact, resistive exercise as the inflammation decreased.

The child continued to improve, and her arthritis was reported to be in remission 5 months after diagnosis. All medications were discontinued, and she had no signs of knee swelling or decrease in ROM. Nine months after the diagnosis, the child developed inflammation of her left ankle. Therefore, NSAIDs were reinitiated and a new physical therapy home program was developed that focused on ankle ROM and strengthening. The ankle inflammation intermittently exacerbated over the next few years without other joint involvement.

The patient, who had been involved in swimming and soccer at the time of diagnosis, had remained actively involved in sports programs throughout the course of her disease. The disease remained well controlled with NSAIDs for the 5 months prior to her request, at age 10 years, for clearance to return to activities requiring greater impact, including competitive basketball.

Information was lacking, however, to determine whether the child could safely participate in high-impact activities. Therefore, the following clinical question was formulated, "Does a child with a history of JRA, but with normal function during activities of daily living, have subtle biomechanical deficits during high-impact sports participation?" The clinical decision was to conduct a comprehensive biomechanical and neuromuscular examination in an attempt to determine the magnitude and distribution of forces on the lower-extremity joints. An additional goal was to attempt to address any identified deficits with a high-intensity neuromuscular intervention program.

Examination: Tests and Measures

Prior to participation in the training protocol, the patient was examined by her rheumatologist, who confirmed the diagnosis of JRA and described the patient's case as quiescent for 2 years. The patient reported no appreciable signs of joint swelling, tenderness, warmth, or joint pain. She did report intermittent, general joint stiffness in the morning that was alleviated with daily activity. A pediatric physical therapist in the Rheumatology Clinic did the musculoskeletal examination, and biomechanists in the Human Performance Laboratory performed the biomechanical examination.

Pain. Pain was assessed using a 0-to-10 visual analog scale. A score of "0" denotes "no pain," and a score of "10" denotes "worst possible pain." The patient reported a score of "0" for all joints at the time of testing.

Range of motion. A single physical therapist (MVP) with more than 10 years of experience in orthopedic physical therapy measured active ROM using a standard goniometer. Researchers[12,13] estimated intratester reliability when assessing knee joint flexion and extension ($r = .97$–$.99$) and lower-extremity ROM in patients without any functional limitations at the knee. Range of motion was measured with the patient in a supine position. She had full ROM of the hips, knees, and ankles.

Gait. The child's gait was assessed using three-dimensional (3-D) motion analysis. She was instrumented with retroreflective markers using the modified Helen Hayes model.[14] Gait analysis techniques have been shown to be reproducible over multiple days for both kinematic and kinetic data (average r=.86).[15] The motion analysis system* consisted of 8 digital (Eagle) cameras connected through an Ethernet hub to the data collection computer and was sampled at 240 Hz. Two force platforms† were sampled at 1,200 Hz and time-synchronized to the motion analysis system. Three trials of data was collected with EvaRT (version 3.21*). Prior to the data collection session, the motion analysis system was calibrated to manufacturer recommendations.

The patient was instructed to walk at a self-selected speed. Kinematic and kinetic data were collected and normalized to 100% of the gait cycle and kinetic data were also normalized to body weight. The patient's gait pattern was near normal[16] with the exception of some clear deviations. During self-selected walking speeds, the patient had increased knee flexion during loading on both the left and right sides. Associated with the increased knee flexion was a higher than normal bilateral external knee flexion moment at initial loading as well as during late stance. She also had increased external knee valgus moments throughout most of the stance phase on both sides. The patient's left foot progression angle during stance suggested an increased toeing in of her left foot compared with normal. Temporal-spatial data indicated that the patient's velocity was comparable and slightly faster than an age-matched normal mean value collected from our laboratory. Fairburn et al[16] conducted a study of gait in patients with JRA and reported that patients with JRA generally have 1 of 4 gait patterns, labeled patterns I, II, III, and IV. Pattern I included increased knee flexion at loading response due to marginally increased stride length and mildly increased external knee varus and valgus moments. All of these gait characteristics were demonstrated by the patient.[16]

Landing technique. Assessment of landing technique was conducted with the same 3-D motion system, marker set, and setup used during gait analysis. The patient executed a box drop test, as described by Ford et al.[17] The box drop test measurements have been shown to have high within-session reliability (r=.94) and between-session reliability (r=89).[17,18] The patient dropped off a 30.5-cm box, with each foot landing on a separate force plate, and then immediately executed a maximum vertical jump with her arms raised overhead, simulating a basketball rebound. The mean peak impact forces from 3 trials on each lower extremity were determined and normalized to body weight. The right lower extremity generated impact forces of 3.9 times body weight, and the right lower extremity generated forces of 2.0 times body weight. Young female athletes without impairments generate approximately 1.5 times body weight on each limb.[19] These results suggest an increase in force on the joints bilaterally between 2 and 4 times the normal force. In addition, a leg dominance effect was observed, demonstrated by the patient's unevenly loaded lower extremities.

Vertical jump test. To measure the patient's overhead reach, she stood directly under the overhead goal (MX-1)‡ and reached (natural overhead reach with no exaggerated superior rotation of the shoulder girdle) directly overhead with both hands reaching up toward the overhead basketball. The midline of the basketball was aligned with the distal interphalangeal joint of the right and left middle fingers. The MX-1 vertical jump tester was zeroed to measured standing reach. To measure her vertical jump, the patient performed a countermovement-only jump off both feet and grabbed the ball with both hands. The height of the MX-1 was adjusted to the maximum height that the patient could grab the ball and hold while landing. The ball height was raised incrementally until she could not pull the ball down from a specific height in 3 trials. The patient's pretraining vertical jump was measured at 25.4 cm, which put her below the 25th percentile for vertical jump (normalized to reach height) compared with girls her age measured on the same device.[20] Authors[21] have estimated the test-retest reliability of countermovement vertical jump testing in adolescent and adult athletes to be r=.99 for males and females.

Muscle strength. Knee extensor and knee flexor strength were assessed isokinetically utilizing a Biodex dynamometer.§ Reliability of isokinetic testing has been estimated to be r=.97 for the quadriceps femoris muscles and r=.85 for the hamstring muscles in children and adolescents.[22] The patient was secured in a seated position on the dynamometer with her trunk perpendicular the floor, her hip flexed to 90 degrees, and her knee flexed to 90 degrees. Stabilization straps were secured at the waist, distal femur, and distal shank, just proximal to the medial malleolus. The test session consisted of 10 knee flexion and extension repetitions for each lower extremity at 300°/s. Peak flexion and extension torques were recorded. She did a warm-up set consisting of 5 knee flexion and extension repetitions for each lower extremity at 300°/s prior to participation. The patient's

* Motion Analysis, 3617 Westwind Blvd, Santa Rosa, CA 95403.

† Advanced Mechanical Technology Inc, 176 Waltham St, Watertown, MA 02172-4800.

‡ MXP Sports Inc, Reading, PA 19612.

§ Biodex Medical Systems, 20 Ramsay Rd, Shirley, NY 11967-4704.

isokinetic knee extension was measured at 36.6 N·m (27 ft-lb) on her right lower extremity and at 33.9 N·m (25 ft-lb) on her left lower extremity. The patient's isokinetic pretest knee flexion measured 10 ft-lb for both lower extremities. The isokinetic measurements revealed hamstring-to-quadriceps femoris muscle strength ratios (right lower extremity=37%, left lower extremity=40%) that were well below the recommended value of 55%.[23]

Postural stability. The patient's postural stability was assessed utilizing the Biodex Stabilometer.[§] The Biodex Stabilometer offers an unstable platform that can assess total, anteroposterior, and mediolateral postural stability. Prior to testing, the subject was asked to find the most stable foot placement on the platform, and this foot position was maintained throughout all 3 trials. This was the reference point from which the center of pressure was measured. She was then instructed to stand on one foot with her knee slightly flexed on the free-moving stability platform and with her contralateral limb flexed to 90 degrees for 20 seconds. The patient was instructed to keep the platform as stable as possible. The stabilometer setting was at level 4 during all tests.[24] The patient was instructed to cross her arms at her chest to minimize their use in attaining balance as outlined in the system operating manual.[25] No verbal feedback was given during the testing, and the patient was given no visual feedback regarding her performance during the test (the control screen was covered during all testing). Each lower extremity was tested 3 times as in previous studies[26,27] using the Biodex Stabilometer for an assessment of postural stability, and the mean of the 3 trials was determined. Results were reported in average degrees of displacement from a stable reference position. A higher score indicates less postural stability. Conversely, the lower the degrees of displacement, the more stable the platform, representing greater postural stability. The Biodex Stabilometer has been shown to provide measurements of total stability index with reliability of $r=.72$.[24] She had a mean postural sway of 3.4 degrees of deflection on the right lower extremity and a mean of 3.3 degrees of deflection on the left lower extremity.

Rationale for intervention. The patient's desire to maintain high levels of activity raised the question of whether sports participation was appropriate. After the initial evaluation, the team of clinicians (physicians and therapists) came to the conclusion that the patient had decreased neuromuscular ability (decreased lower-extremity strength and power, decreased ability for force attenuation and postural control) in the areas measured, which might increase her risk for a musculoskeletal injury.[28–30] The decreased neuromuscular function may have been related to JRA, which concerned the team not only because of potential risk for an acute injury, but also because of the potential for a recurrence of chronic joint inflammation due to abnormally high forces on a compromised joint.[11] The examination results expanded the thinking into a multidisciplinary decision-making approach that bridged the divisions of rheumatology, physical therapy, and sports medicine. A novel method was developed to address the neuromuscular deficiencies present in this patient.

Previously, authors[23,29] have reported that some female athletes may have one or more neuromuscular deficiencies that can put them at risk for knee injury during sports play. Neuromuscular training utilizing plyometrics, resistance training, and stabilization training combined with technical feedback on performance has been shown to decrease neuromuscular imbalances related to injury risk and improve measurements of performance in athletics.[29,31] It has not been shown that patients with JRA demonstrate neuromuscular deficiencies that put them at risk for sports injuries. More importantly, it has not yet been demonstrated whether specialized neuromuscular training (SNT) or neuromuscular training focused on improving force attenuation strategies can safely be administered to young patients with JRA to address neuromuscular deficiencies that are related to injury risk.[29]

Intervention

The primary goal of the neuromuscular training was to prepare the patient for sports competition. Specifically, the goals were to increase force dissipation on landing, to increase hamstring muscle strength and recruitment, and to decrease bilateral lower-extremity force asymmetries that are related to risk for injury during competitive sports.[28,29,32] Other goals were to reduce the patient's gait deviations to measurements similar to those of age-matched typical subjects, to minimize joint stress, to improve symmetry in agonist/antagonist and contralateral strength measurements, and to maintain joint active ROM to prepare the patient for safe and pain-free sports participation.

Intervention

A certified strength and condition specialist with more than 10 years of experience in training competitive athletes administered the intervention in collaboration with a physical therapist with more than 10 years of experience in a sports medicine rehabilitation setting. The neuromuscular training occurred 2 times a week for 5 weeks. Prior to each training session, the patient was questioned about joint pain with palpation and swelling was visually assessed.

Warm-up (Gait Training)

The patient performed a 5-minute warm-up of gait training with intermittent walking and running. The gait training program emphasized symmetry of lower-extremity muscular contribution to help prevent abnormal loading of the ligaments and soft tissue. The gait training was done on a treadmill, which allowed technical feedback during each running bout. Incline treadmill running was used to increase hip flexion ROM and flexor strength.[33] The patient reported decreased knee pain when running at increased elevations. Evidence suggests that retrograde (backward) treadmill training also can be used to minimize knee joint loads.[34] Once the patient could attain lower-extremity symmetry during submaximal running, treadmill speeds were increased to assess her sprinting form. Attention was directed toward obtaining a normal rhythmical stride. An unbalanced sprinting rhythm is indicative of unbalanced limb contribution and is most evident through monitoring the audible magnitude of foot contact. If the athlete has the problem of unbalanced sprinting gait, the contributing factor is likely either pain or limited ROM in the involved lower extremity.[35,36] If pain limited symmetrical gait, then more backward running was used during the next training session of training. Pain-free symmetrical running gait was the ultimate goal of the treadmill gait training portion of the intervention.

Landing Technique

After each gait training warm-up, about 10 minutes of the training focused on progressive landing and plyometric training. This portion of the protocol was used to teach the patient to properly initiate, control, and decelerate ground reaction forces. Plyometric training can increase bone density in young females and is recommended as a safe and worthwhile method of conditioning children under proper supervision.[37,38] Special attention was directed toward the patient's landing, because she demonstrated limb inequality and high ground reaction forces in her pretest measurements. The high peak ground reaction forces during landing or cutting may be associated with force-dissipating strategies that rely mainly on reducing joint forces with passive restraints (ligaments, subchondral bone, articular cartilage, and meniscus) instead of using active muscular restraints involved in joint flexion.[35,36,39] During the training, the overriding focus was to teach the patient to decrease lower-extremity joint load magnitude through increased active sagittal-plane joint flexion and to avoid excessive lower-extremity coronal-plane movements. Lower-extremity coronal-plane joint loads have been associated with increased ground reaction forces and risk for sports injury.[29,39] Landing strategies that incorporate abnormal levels of coronal-plane movement also may increase articulation point contact stress by decreasing surface area contact, which may predispose the cartilage to failure.[5] Repetitive high joint loads with poor load dissipation strategies have been suggested to cause osteoarthritis in athletes.[36] The effects of abnormal joint loads on patients with JRA may have detrimental effects to an ever greater extent due to compromised joint articular cartilage.

Technique-intensive neuromuscular training may provide athletes with biomechanical adaptations that can prepare them to respond to the extreme forces generated during athletic competition.[39–41] The progressive nature of neuromuscular training for athletes without impairments is designed to take them to an endpoint where they can properly initiate, control, and decelerate ground reaction forces that they will encounter in competitive play when jumping, landing, and cutting. However, it was determined that a protocol progression for a patient with JRA must incorporate an appropriate balance between developing the patient's proprioceptive abilities[35] (eg, postural stability, lower-extremity joint control) and exposing the patient to an at-risk movement that causes pain, inflames a joint, or puts the patient at risk for injury.

Initially, low-intensity movement such as a line jump and hold (hold the end position for 3–5 seconds) or a box drop and hold were used to teach the patient to attempt to gain proper joint kinesthesia during jumping and landing. To attempt to decrease the magnitude of ground reaction force, the patient was taught to use more knee and hip flexion when landing and cutting to allow her to dissipate force over the greater time and lessen the impulse of impact forces early in the stance phase of landing. A secondary focus was to teach her to control knee motion in the coronal plane. She was taught to view the knee as a single-plane hinge joint and not a ball-and-socket joint. The first step was to make her aware of proper form and technique as well as undesirable and potentially dangerous positions. Visual feedback was given through the use of videotape and exercise in front of a mirror to make her aware of landings with identifiable medial knee motion. The trainer provided continuous and critical technical feedback to bridge the patient's perceived technique and her actual performance. In the later sessions of some power jumps such as broad jumps, broad jump vertical and overhead goal jumps for maximal effort were included. These jumps were used to help increase the patient's power; however, technique assessment and feedback were continuously given to help the patient maintain optimal biomechanics during the more power-oriented jumps.

After the patient gained more desirable mechanics during the low-intensity movements as assessed through observation, the difficulty level was progressively increased by adding targets for jumping drills and incorporating unanticipated elements to the cutting drills. Single-faceted sagittal-plane training and conditioning protocols that do not incorporate multidirectional cutting maneuvers may not provide similar levels of external coronal- or transverse-axis joint loads that are seen during sport-specific cutting maneuvers.[42] Neuromuscular technique training that incorporates safe levels of coronal- or transverse-axis joint stress may induce more "muscle dominant" neuromuscular adaptations.[42] Such adaptations may better prepare athletes for more multidirectional sport activities that can improve their performance and reduce risk for lower-extremity injury.[39,41,43] Inherently, female athletes tend to perform cutting techniques with decreased knee flexion and increased valgus angles.[44] Coronal-plane loads can double when performing unanticipated cutting maneuvers similar to those used in sports.[45] The goal of the technique-oriented training, which was designed to reduce this patient's overall joint loading via valgus torques, was to teach movement techniques that produce the low abduction moments at the knee.[42] Prior research demonstrated that SNT, which incorporates unanticipated pivoting and cutting maneuvers, reduces knee joints loads.[31] Additionally, by improving reaction times to provide more time to voluntarily precontract the lower-extremity musculature and make appropriate kinematic adjustments, the patient might be better prepared to reduce knee joint loads during competitive play.[45,46]

Unanticipated Training

Prior to the initiation of unanticipated cutting drills, the patient became proficient at achieving proper athletic position in other technical drills. The athletic position is a functionally stable position with the knees comfortably flexed, shoulders back, eyes up, feet approximately shoulder-width apart, and body mass balanced equally over the balls of both feet.[39,41] This was the patient's ready position and was the starting and finishing position for most of the training exercises. This was the goal position to achieve prior to initiating an unanticipated directional cut. The unanticipated directional cut and run techniques utilized directional cues to provide unanticipated nature to the tasks. The directional cueing portion of training can be as simple as pointing or as sports-specific as using partner-mimic or ball-retrieval drills. The purpose of training the patient to use safe cutting techniques in unanticipated sports situations was to instill technique adaptations that may more readily transfer onto the field of play.

Limb Symmetry

To attempt to correct the large bilateral discrepancy in the patient's lower-extremity functional ability, the technique training progressively emphasized double-leg then single-leg movements. During the training, equal leg-to-leg strength, balance, coordination, and foot placement were emphasized. Initially, during bipedal stance, the patient continuously overloaded her dominant (right) lower extremity, which was previously asymptomatic for knee and ankle inflammation. By forcing her to maintain parallel foot placement during bipedal activities, the nondominant limb may have been forced to accept a greater load in order to maintain symmetry throughout the performance of double-leg jumps. This increased stress may aid in the increased neuromuscular adaptation in the weaker involved limb. For example, when the patient performed a difficult exercise such as squat jumps, she demonstrated her lower-extremity asymmetry. She did not provide equal force output from each lower extremity, making it difficult to limit her body's coronal-plane displacement. To perform bipedal jumps, her weaker, less-coordinated lower extremity may have experienced increased stress to maintain symmetrical positioning with the stronger lower extremity. In turn, the desired neuromuscular adaptations may have occurred more readily in the weaker limb.

Even though specific feedback was given to the patient regarding her foot placement during landing and jumping, she tended to drop her dominant or stronger lower extremity posterior to the less-coordinated lower extremity when performing double-leg jumps. This was not the desired technique, because it may have facilitated lower extremity imbalances by overloading the stronger lower extremity while unloading the stress on the weaker lower extremity. To counteract this problem, single-leg hop-and-hold exercises were introduced to the training. The single-leg drills were used to force each limb to work independently of the other limb in situations where compensation cannot be provided by the contralateral limb. The addition of the single-leg hop-and-hold exercises may help create greater muscular adaptations in the weaker limb to help decrease the limb-to-limb imbalances.

Core Strength

Core strengthening and stability training was the final component used during the patient's training and was about 20–30 minutes of each training session. Reduced postural balance has been related to increased risk for lower-extremity injury.[30] Training that incorporates core strengthening and balance training can improve postural control and reduce the risk for injury.[24,30,47] The initial goal was to improve the patient's ability to maintain bipedal stance in the athletic position on a stable surface, which was emphasized during the jumping technique portion of her training.

During the beginning stages of the core strengthening and stability training, progressions were made from decreasing the frequency of double-limb jumps and increasing the frequency of single-limb hops. Balance on an unstable surface also was introduced using bilateral stance exercises. The "Both sides up" (BOSU) balance training device[||] was used for unstable surface training. The BOSU balance device provides an unstable platform for use in decreasing surface stability to the lower extremity. Progressively, the patient used more single-limb stance movements with a decrease in double-limb stance on stable surfaces. In addition, bipedal stable surface activities progressed to more multiplanar movements.

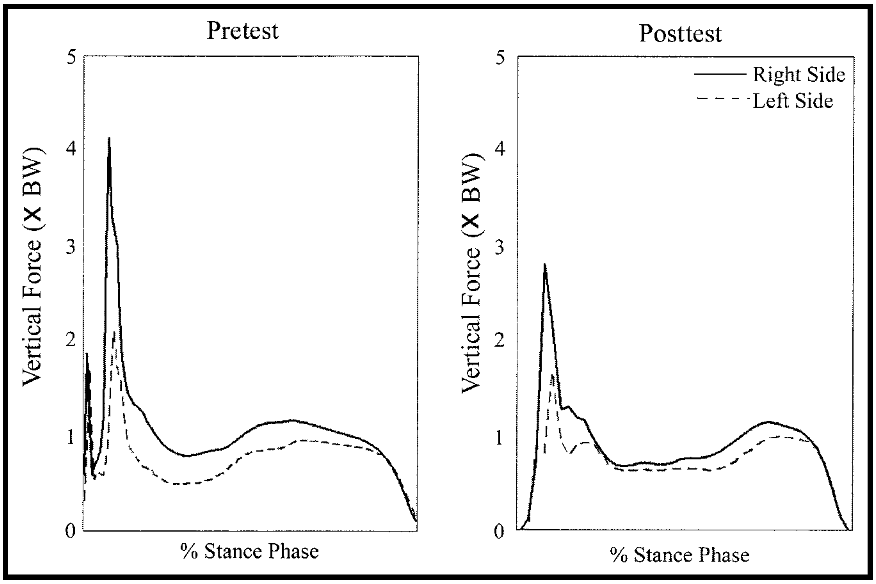

Figure 1.
Right- and left-side vertical ground reaction forces (times body weight [BW]) during stance when performing the pretest and posttest box drop vertical jump.

Training then advanced to single-limb stance drills on a stable surface. Single-limb stance intensity was progressed with the addition of single-plane, low-intensity hops or external perturbations (ie, technical cues and physical pushes) to progressively increase intensity. As single-limb balance improved, the patient was encouraged to increase hip and knee flexion during stance. She also was encouraged to take visual focus forward, away from her feet. Ball tosses were incorporated to attract visual attention and provide a distraction from the balance task. The final sessions included single-limb static holds with upper-extremity perturbations as well as bipedal stance maneuvers such as jumping onto and off the unstable surface in multiple planes and rotational jumps on the unstable platform. The focus of the late stages of training was to develop stability in a single-limb stance position in unstable and unanticipated environments, with the goal of preparing the patient to react appropriately in an athletic situation.

The core strengthening portion of the training incorporated body weight strength maneuvers that required a high degree of balance and coordination. The lower-extremity strengthening progressed from bipedal squatting exercises to multiple-angle lunge exercises to single-limb squatting exercises. Resistive bands were used while she performed various multidirectional sports-related movements. Abdominal, mid and low back, and hip strength exercises also were conducted on unstable surfaces (BOSU Balance Trainer,[||] Airex Balance Pad,[#] Swiss Ball[#]). Hakkinen[48] previously demonstrated that patients with RA have long-term benefits from strength training.

Introduction of all of the components of this type of training created some delayed-onset muscle soreness. To maintain the patient's flexibility and decrease delayed-onset muscle soreness (reported by the patient), a 5-minute passive stretching session was conducted at the end of each training session. The patient was monitored for any signs of joint inflammation. The daily protocol was modified frequently to provide the appropriate intensity and progression of exercises to prevent exacerbation of any symptoms in the affected joints. Pain in a joint was always the overriding determinant to exercise selection and performance. As the patient acclimated to the training, she increased her ability to differentiate between joint pain and muscular fatigue. Through open communication between the therapist and patient, the ability to increase intensity while limiting pain became more efficient in the later training sessions.

Outcomes

The patient's post-training performance was compared with pretest measurements and data on sex- and age-matched children who are healthy. Prior to each training session, the patient was questioned to assess her pain. Initially during the neuromuscular training, the patient reported mild joint pain the day after a training session. As the training progressed, the joint pain subsided to a point where she would report no joint pain before, during, or after training sessions. The patient's mother reported that the general joint stiffness in the mornings had decreased noticeably after going through the training. Stiffness can be an indicator of joint inflammation and is included on the parent reports of some standardized quality-of-life scales.[49]

The patient's gait pattern improved to within a normal range (±1 standard deviation) with respect to knee flexion angle at initial contact on both the right and left

[||] Team BOSU, 1400 Raff Rd, Canton, OH 44750.
[#] Perform Better Inc, 11 Amflex Dr, PO Box 8090, Cranston, RI 02920-0090.

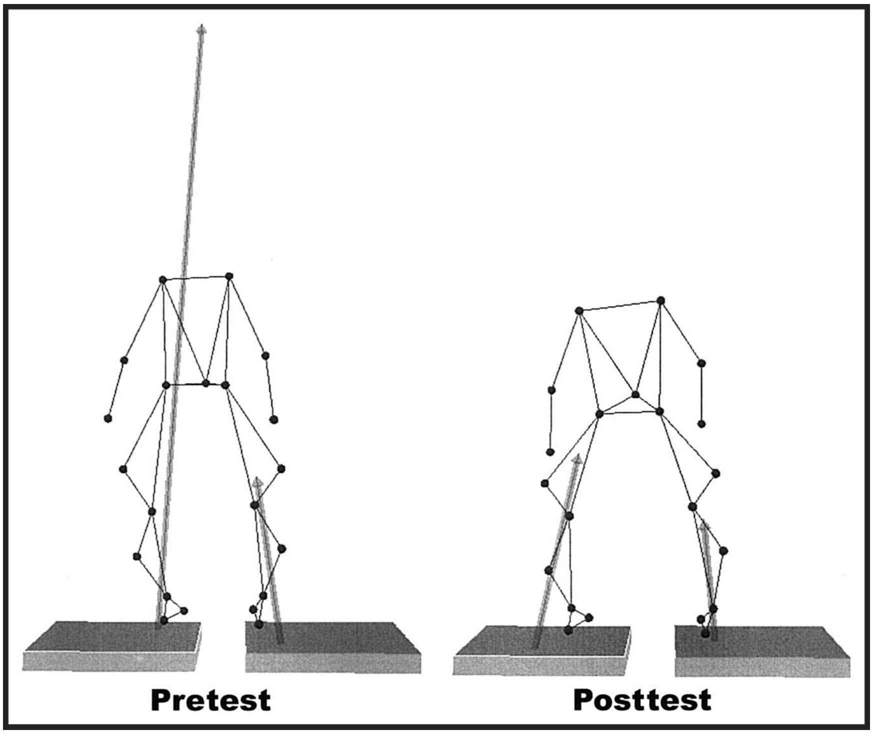

Figure 2.
Illustrations of side-to-side differences in pretest and posttest kinematics and kinetics of the box drop vertical jump. The pretest vectors help demonstrate the side-to-side differences in the magnitude of the vertical ground reaction forces. The posttest vectors demonstrate the patient's reduction of impact force and bilateral asymmetries when landing after specialized neuromuscular training.

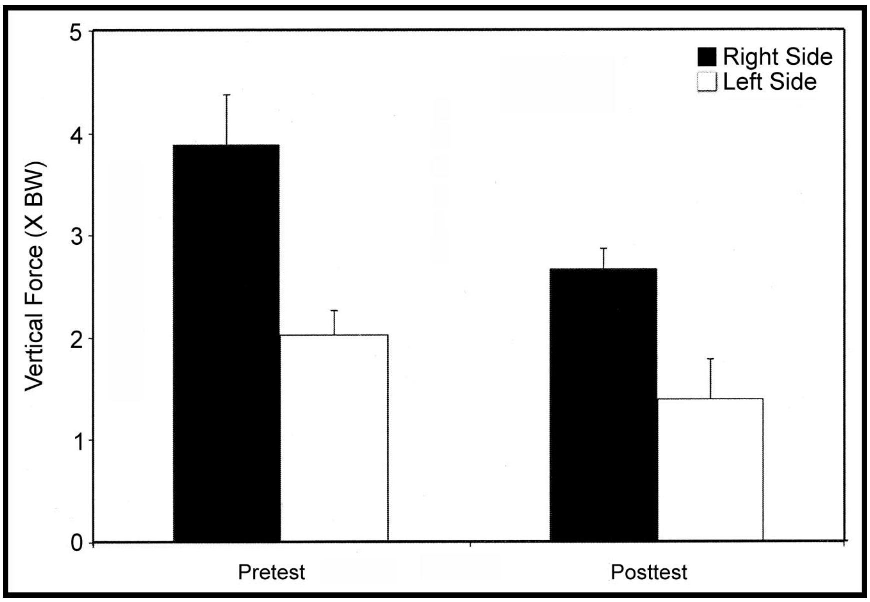

Figure 3.
Pretest and posttest comparison of right- and left-side peak vertical force during the initial landing of the box drop vertical jump test.

sides. She continued to slightly overflex her knees during loading response of gait. Her external knee flexion moment on both sides did not change from the pretest measurements. The patient's right external varus moment during the gait cycle improved to within normal limits. In addition, high external valgus moments decreased during mid-stance at the left knee. Temporal-spatial data showed a change in step width from 8.2 to 12 cm during the posttest (normal: 11±2 cm).

Measurements for 3 trials of a box drop vertical jump were collected before and after intervention. Her initial peak force calculation identified a large side-to-side imbalance during the landing phase (Figs. 1 and 2). Upon completion of the physical therapy, there was still a side-to-side difference in peak force; however, the difference decreased by 46% and total peak force decreased on both sides by 31% (Fig. 3). The side-to-side difference in her knee flexion angle at contact decreased to only a 3-degree difference during the posttest compared with a difference of nearly 10 degrees at the initial testing.

The patient's strength and balance were determined prior to and immediately after the physical therapy intervention program. Strength was measured on an isokinetic dynamometer at high speed (300°/s). The patient improved her hamstring muscle strength by 85% on the right side and by 113% on the left side. She also increased her quadriceps femoris muscle strength by 18% on the right side and by 26% on the left side. The increased relative hamstring muscle strength improved the patient's hamstring-to-quadriceps femoris muscle ratio (Fig. 4).

The patient's single-leg balance was assessed on a stabilometer (lower scores relate to better balance). Balance on her right lower extremity improved from a stability index score of 3.4 degrees of deflection to 1.5 degrees of deflection (56% improvement), and her balance on her left lower extremity improved from a stability index score of 3.3 degrees of deflection to 1.8 degrees of deflection (46% improvement) (Fig. 5). Mean total postural stability for pubertal normative data from our laboratory is 3.4 on the right limb and 3.7 on the left limb. This patient had initial values similar to the

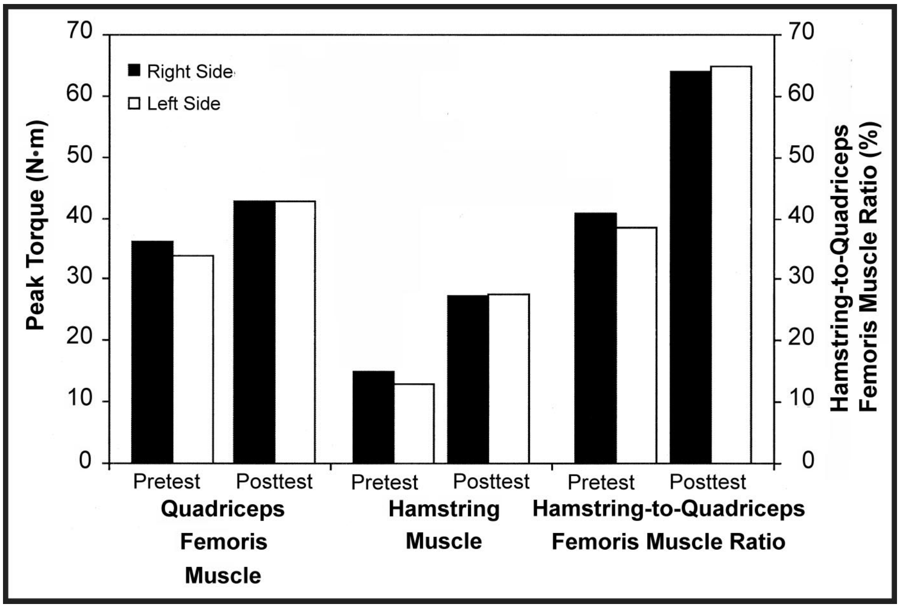

Figure 4.
Peak torque (in newton-meters) measured on a Biodex isokinetic dynamometer. Results shown for both right- and left-side measurements of flexion, extension, and hamstring-to-quadriceps femoris muscle ratio.

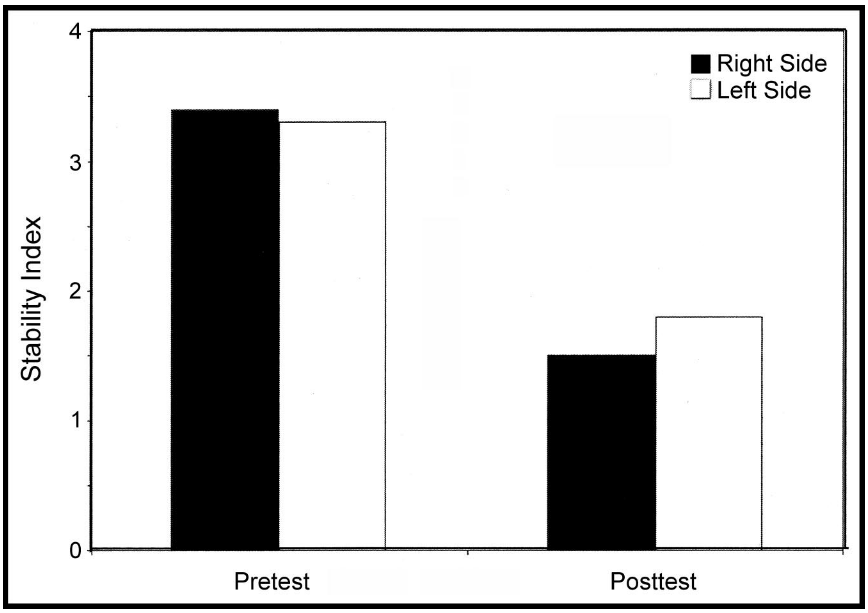

Figure 5.
Pretest and posttest comparison of total stability index (in square centimeters) measured on a Biodex Stabilometer at stability level 4. Results shown for both right- and left-side balance measurements.

normative values. Previous studies in athletes without balance disorders have linked balance measures to injury risk and suggest that improvement with postural control may be beneficial for injury prevention.[24,30,50–52] Therefore, this improvement in stability above the baseline of the controls could potentially assist in decreasing our patient's risk for injury.

Discussion and Conclusions

Juvenile rheumatoid arthritis is a disease characterized by periods of quiescence and exacerbation. In times of quiescence, when patients may have normal ROM and normal strength, the underlying disease is still present, which results in difficult decisions about participation in high-impact activities. Even though pain may be absent, the potential presence of underlying biomechanical and neuromuscular deficits and ultimately the long-term implications of high-impact loading are unknown. Currently, the literature is limited with respect to evidence of the relevance of these deficits in children with JRA as well as the efficacy of SNT as an intervention.

In this case, a patient with normal ROM and strength and no reports of pain had abnormal biomechanics, which may place her at higher risk for injuries and joint degeneration.[29] Short-term SNT was followed by measurable improvement of the biomechanics of gait and athletic movements of this patient. Our experience suggests that low-impact, multiplanar, technique-oriented movements that are a challenge to the neuromuscular system can be safely instituted for a patient with quiescent JRA. We feel the exercises selected should challenge the dynamic joint restraints (muscle-tendon units) that maintain lower-extremity control of joint position in response to changing loads. Sports-related technique and movement training may provide an athlete with an effective means for facilitating the desired adaptations to joint proprioception that may carry over into functional activities and possibly sport competition.[31] The jumping and landing components should be appropriately progressed to ensure that adequate neuromuscular function is available to prevent disease exacerbation or acute onset of lower-extremity joint inflammation. Proper technical performance during athletics may allow patients with JRA to use joint loading techniques that allow sport-specific maneuvers to be performed in a safe and controlled manner.[29,39,41] This is important for patients who desire to be involved in sport-related activities for overall exercise and fitness. Past participation in exercise-related activities has been found to be a strong predictor of future exercise habits for people with arthritis.[53] Therefore, it would seem appropriate to establish effective strategies for assessment and exercise administration to facilitate sport participation in children with JRA.

This case report describes a novel approach to training patients with quiescent JRA to help them enter sports with potentially decreased risk for injury and increased performance. However, due to the lack of controls and variability of patients with JRA, the outcomes cannot be generalized to other types of patients. Further investigation into the effectiveness of SNT for children with JRA is warranted.

References

1 Weiss JE, Ilowite NT. Juvenile idiopathic arthritis. *Pediatr Clin North Am.* 2005;52:413–442.

2 Lawrence RC, Helmick CG, Arnett FC, et al. Estimates of the prevalence of arthritis and selected musculoskeletal disorders in the United States. *Arthritis Rheum.* 1998;41:778–799.

3 Reiff AO. Developments in the treatment of juvenile arthritis. *Expert Opin Pharmacother.* 2004;5:1485–1496.

4 Emery HM, Bowyer SL, Sisung CE. Rehabilitation of the child with a rheumatic disease. *Pediatr Clin North Am.* 1995;42:1263–1283.

5 Mow VC, Proctor CS, Kelly MA. Biomechanics of articular cartilage. In: Nordin M, Frankel VH, eds. *Basic Biomechanics of the Musculoskeletal System.* 2nd ed. Philadelphia, Pa: Lea & Febiger; 1989:53.

6 Klepper SE. Exercise and fitness in children with arthritis: evidence of benefits for exercise and physical activity. *Arthritis Rheum.* 2003;49: 435–443.

7 Simeonsson RJ, Leonardi M, Lollar D, et al. Applying the International Classification of Functioning, Disability and Health (ICF) to measure childhood disability. *Disabil Rehabil.* 2003;25:602–610.

8 Guidelines for the management of rheumatoid arthritis: 2002 update. *Arthritis Rheum.* 2002;46:328–346.

9 Munneke M, de Jong Z, Zwinderman AH, et al. Adherence and satisfaction of rheumatoid arthritis patients with a long-term intensive dynamic exercise program (RAPIT program). *Arthritis Rheum.* 2003;49: 665–672.

10 de Jong Z, Munneke M, Zwinderman AH, et al. Is a long-term high-intensity exercise program effective and safe in patients with rheumatoid arthritis? Results of a randomized controlled trial. *Arthritis Rheum.* 2003;48:2415–2424.

11 Finckh A, Iversen M, Liang MH. The exercise prescription in rheumatoid arthritis: primum non nocere. *Arthritis Rheum.* 2003;48: 2393–2395.

12 Watkins MA, Riddle DL, Lamb RL, Personius WJ. Reliability of goniometric measurements and visual estimates of knee range of motion obtained in a clinical setting. *Phys Ther.* 1991;71:90–96; discussion 96–97.

13 Boone DC, Azen SP, Lin CM, et al. Reliability of goniometric measurements. *Phys Ther.* 1978;58:1355–1390.

14 Kadaba MP, Ramakrishnan HK, Wootten ME. Measurement of lower extremity kinematics during level walking. *J Orthop Res.* 1990;8: 383–392.

15 Kadaba MP, Ramakrishnan HK, Wootten ME, et al. Repeatability of kinematic, kinetic, and electromyographic data in normal adult gait. *J Orthop Res.* 1989;7:849–860.

16 Fairburn PS, Panagamuwa B, Falkonakis A, et al. The use of multidisciplinary assessment and scientific measurement in advanced juvenile idiopathic arthritis can categorise gait deviations to guide treatment. *Arch Dis Child.* 2002;87:160–165.

17 Ford KR, Myer GD, Hewett TE. Valgus knee motion during landing in high school female and male basketball players. *Med Sci Sports Exerc.* 2003;35:1745–1750.

18 Ford KR, Myer GD, Hewett TE. Reliability of dynamic knee motion in female athletes. Paper presented at: 27th Annual Meeting of the American Society of Biomechanics; September 25–27, 2003; Toledo, Ohio.

19 Paterno MV, Ford KR, Myer GD, et al. Biomechanical limb asymmetries in female athletes 2 years following ACL reconstruction. Abstract presented at: Combined Sections Meeting of the American Physical Therapy Association; February 23–27, 2005; New Orleans, La.

20 National percentile rankings. In: *Exploder Training Manual.* Reading, Pa: MXP Sports Inc; 2001.

21 Stockbrugger BA, Haennel RG. Validity and reliability of a medicine ball explosive power test. *J Strength Cond Res.* 2001;15:431–438.

22 Hewett TE, Myer GD, Ford KR. Decrease in neuromuscular control about the knee with maturation in female athletes. *J Bone Joint Surg Am.* 2004;86:1601–1608.

23 Hewett TE, Myer GD, Ford KR. Prevention of anterior cruciate ligament injuries. *Current Women's Health Reports.* 2001;1:218–224.

24 Paterno MV, Myer GD, Ford KR, Hewett TE. Neuromuscular training improves single-limb stability in young female athletes. *J Orthop Sports Phys Ther.* 2004;34:305–317.

25 *Balance System Operation and Service Manual (#945–300).* Shirley, NY: Biodex Medical System; 2000.

26 Rozzi SL, Lephart SM, Gear WS, Fu FH. Knee joint laxity and neuromuscular characteristics of male and female soccer and basketball players. *Am J Sports Med.* 1999;27:312–319.

27 Schmitz R, Arnold B. Intertester and intratester reliability of a dynamic balance protocol using the Biodex Stability System. *Journal of Sport Rehabilitation.* 1998;7:95–101.

28 Knapik JJ, Bauman CL, Jones BH, et al. Preseason strength and flexibility imbalances associated with athletic injuries in female collegiate athletes. *Am J Sports Med.* 1991;19:76–81.

29 Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes. *Am J Sports Med.* 2005;33:492–501.

30 Tropp H, Ekstrand J, Gillquist J. Stabilometry in functional instability of the ankle and its value in predicting injury. *Med Sci Sports Exerc.* 1984;16:64–66.

31 Myer GD, Ford KR, Palumbo JP, Hewett TE. Neuromuscular training improves both performance and lower extremity biomechanics in female athletes. *J Strength Cond Res.* 2005;19:51–60.

32 Baumhauer J, Alosa D, Renstrom A, et al. A prospective study of ankle injury risk factors. *Am J Sports Med.* 1995;23:564–570.

33 Swanson SC, Caldwell GE. An integrated biomechanical analysis of high speed incline and level treadmill running. *Med Sci Sports Exerc.* 2000;32:1146–1155.

34 Flynn TW, Soutas-Little RW. Patellofemoral joint compressive forces in forward and backward running. *J Orthop Sports Phys Ther.* 1995;21: 277–282.

35 Hewett TE, Paterno MV, Myer GD. Strategies for enhancing proprioception and neuromuscular control of the knee. *Clin Orthop.* 2002; 402:76–94.

36 Radin EL. Mechanical aspects of osteoarthrosis. *Bull Rheum Dis.* 1976;26:862–865.

37 Faigenbaum AD, Chu DA. Plyometric training for children and adolescents. *American College of Sports Medicine Current Comment.* December 2001.

38 MacKelvie KJ, Khan KM, Petit MA, et al. A school-based exercise intervention elicits substantial bone health benefits: a 2-year randomized controlled trial in girls. *Pediatrics.* 2003;112(6 pt 1):e447.

39 Hewett TE, Stroupe AL, Nance TA, Noyes FR. Plyometric training in female athletes: decreased impact forces and increased hamstring torques. *Am J Sports Med.* 1996;24:765–773.

40 Hewett TE, Paterno MV, Noyes FR. Differences in single leg balance on an unstable platform between female and male normal, ACL-deficient and ACL-reconstructed knees. In: Lephardt S, Fu FH, eds. *Proprioception and Neuromuscular Control in Joint Stability.* Champaign, Ill: Human Kinetics Inc; 1999:77–88.

41 Myer GD, Ford KR, Hewett T. The effects of gender on quadriceps muscle activation strategies during a maneuver that mimics a high ACL injury risk position. *J Electromyogr Kinesiol.* 2005;15:181–189.

42 Lloyd DG. Rationale for training programs to reduce anterior cruciate ligament injuries in Australian football. *J Orthop Sports Phys Ther.* 2001;31:645–654; discussion 661.

43 Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes: a prospective study. *Am J Sports Med.* 1999;27:699–706.

44 Malinzak RA, Colby SM, Kirkendall DT, et al. A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clin Biomech (Bristol, Avon).* 2001;16:438–445.

45 Besier TF, Lloyd DG, Cochrane JL, Ackland TR. External loading of the knee joint during running and cutting maneuvers. *Med Sci Sports Exerc.* 2001;33:1168–1175.

46 Neptune RR, Wright IC, van den Bogert AJ. Muscle coordination and function during cutting movements. *Med Sci Sports Exerc.* 1999;3: 294–302.

47 Caraffa A, Cerulli G, Projetti M, et al. Prevention of anterior cruciate ligament injuries in soccer: a prospective controlled study of proprioceptive training. *Knee Surg Sports Traumatol Arthrosc.* 1996;4: 19–21.

48 Hakkinen A. Effectiveness and safety of strength training in rheumatoid arthritis. *Curr Opin Rheumatol.* 2004;16:132–137.

49 Varni JW, Seid M, Smith Knight T, et al. The PedsQL in pediatric rheumatology: reliability, validity, and responsiveness of the Pediatric Quality of Life Inventory Generic Core Scales and Rheumatology Module. *Arthritis Rheum.* 2002;46:714–725.

50 McGuine TA, Greene JJ, Best T, Leverson G. Balance as a predictor of ankle injuries in high school basketball players. *Clin J Sport Med.* 2000;10:239–244.

51 Holme E, Magnusson SP, Becher K, et al. The effect of supervised rehabilitation on strength, postural sway, position sense and re-injury risk after acute ankle ligament sprain. *Scand J Med Sci Sports.* 1999;9: 104–109.

52 Ross SE, Guskiewicz KM. Examination of static and dynamic postural stability in individuals with functionally stable and unstable ankles. *Clin J Sport Med.* 2004;14:332–338.

53 Iversen MD, Fossel AH, Ayers K, et al. Predictors of exercise behavior in patients with rheumatoid arthritis 6 months following a visit with their rheumatologist. *Phys Ther.* 2004;84:706–716.