Preconditioning Principles for Preventing Sports Injuries in Adolescents and Children

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In the United States, more than 30 million children and teenagers are expected to participate in all levels of sports and recreational activities. Even with the best coaching and training facilities, 3\% to 11\% of these children between the ages of 5 and 15 years old become injured. National statistics provided by the National Safe Kids Campaign and the American Academy of Pediatrics have disclosed that 3.5 million injuries each year occur within this 5- to 14-year-old age group. Hospital emergency rooms may expect up to 775,000 injuries to children in this age group. This age group comprises roughly 40\% of all emergency room visits for sports-related injuries. The two major injury groups include acute traumatic injuries and overuse injury syndromes. The demands of individual, team, and recreational sports may account for the different injury occurrences within each group. Although the prevalence of injuries in organized sports tends to dominate in the age group from 9 to 14 years old, in younger age groups, both playground entry level and bicycle injuries usually account for the remainder. The practitioner providing medical service to any organized sports program should be aware of the percentage of athletes injured within specific sports and the specific types of injuries unique to the sport (Fig. 1). Typically, the following percentages

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of players are injured in these specific sports: (1) basketball, 15%; (2) football, 20%; (3) soccer, 22%; (4) baseball, 25%; and (5) softball, 12%. As the demand for greater competitive performance filters down into the younger age groups, prolonged practice routines are now accounting for almost 50% of all overuse injuries encountered in the middle- and high-school years [1]. Sixty percent of all injuries incurred in organized sports-related activities often occur from organized practice sessions. It is the goal of this article to present principles of pre-conditioning and injury prevention.

Injury prevention

The causes of sports-related injuries is related to the physiologic age of the youth athlete rather than to chronologic age [2]. The dynamics of any sport place extraordinary demands on individual tissue systems that are dependent on the status of the epiphysis, bone structure, and general growth status [3]. Not all tissue systems are at equal risk for damage. In the case of soft tissue muscle-tendon injuries, most follow two general patterns: injuries to muscle-tendon units crossing two joints and injuries to muscle-tendon units that decelerate joints by excessive tension from eccentric muscle contractions [4]. Most commonly, muscles whose origin and insertion cross two joints are most vulnerable to injury [2]. Typical examples in this group are the Hamstrings and Achilles tendons. Because these muscles span two joints, they may experience extensive tensile elongation, producing tears in their fibers. The next most vulnerable muscle groups tend to be those muscles that experience an eccentric contraction to decelerate motion at a joint. An eccentric contraction is one in which muscle
tension increases in a muscle as it contracts to resist a force that attempts to overstretch the muscle’s length. A common example of an eccentric stretch would be the increasing tension in the biceps muscles of the arm holding a steady position at the elbow while a hand weight is gradually lowered onto a table. The quadriceps tendon is another eccentric muscle unit that provides eccentric resistance while preventing hyperflexion of the knee at heel strike in runners. Another eccentric example is the anterior extensor muscles of the tibia. These muscles slow the dropping of the forefoot at heel strike in a gradual manner through an eccentric contraction. Overuse of these extensor muscle units creates susceptibility to periosteal tears at their origin, creating “shin splints.”

Injury prevention starts with identifying the causes and factors of poorly conditioned athletes. Such factors include improper training techniques, environmental hazards, physiologic weakness, and nutritional status. This article focuses on improper training techniques and cites where intensity, duration, and training frequency can induce pathologic problems in the lower extremity. The basic concepts in preseason conditioning and the vocabulary that sports medicine specialists must know to converse intelligently with coaches, trainers, and strengthconditioners are emphasized.

**Preseason screening: Tanner Body Index**

A child’s physiologic age is predominantly more important than his or her chronologic age in assessing individual ability to acclimate functionally to a specific youth sport. The Tanner Body Index is a method of classifying the youth athlete according to his or her physiologic development with pubescent maturation [5]. The Index has four classifications: stages I, II, III, and IV. For boys, maturation is based on the growth of pubic hair and genitalia. For girls, staging is based on breast formation. Early prepubescent Tanner stages I and II are characterized by pretestosterone level increases and immaturity in the musculoskeletal system. Youths in this stage are best assigned to nonimpact sports, such as running. Tanner stages III (midpubescent) and IV (postpubescent) are characterized by periods of growth and skeletal maturation. At the midpubescent stage III (boys aged 12–15 year, girls aged 10–13 years), it is precisely these growth spurts that make the child most vulnerable to injury in two basic ways: joint tightness with limiting ranges of motion and peak epiphyseal vulnerability. Growth spurts may create asymmetry of long bones and an imbalance in opposing muscle-tendon units. The subchondral bone and physis become easily susceptible to microtrauma [3]. Associated muscles and tendons must stretch out to meet these new bone lengths. The muscles become functionally short while accommodating to new bony anatomic lengths. This tightness limits the effective range of motion about their respective joints. As an example, Achilles tendon equinus is often the precursor to calcaneal apophysitis and pronation syndromes in the foot. During this time, flexibility programs must be instituted to regain lost range of motion about these tightened joint structures.
Tanner stage III prepubescent youths (aged 11–13 years) are experiencing a period of peak gain in height. Such growth spurts produce stress points at the expanding physis at its weakest time. Impact sports are most apt to induce disturbances with growth plates at this stage [6]. Such concern should be monitored in Tanner stage III youths.

Regardless of the extent of preseason physical examinations and body indexing, three basic areas of functional skills evaluation are important. Three most useful functional tests are; the Functional Romberg Test for postural balance and pelvic strength integrity, the 150% Body Strength Rule for general muscle strength, and the Agility Index for neuromuscular reactivity [7].

**Functional Romberg Test**

This test evaluates the athlete’s ability to handle weight loads about the axial skeleton during sport activity to maintain balance. The Functional Romberg Test specifically evaluates the ability of muscles about the pelvic girdle to stabilize balance. The athlete is asked to stand and balance upright over a single limb. In performing this drill, the athlete should be able to stand upright and one legged on the supporting limb. This position is held for 30 seconds without tilting or angling the upper torso over the support leg for balance. Alternately, on command, the youth athlete should be able to stand up onto his or her toes 10 times without excessively shifting his or her body position or losing balance. Any tendency for the athlete to sway or swagger over the support limb raises suspicion regarding inadequate strength to stabilize the pelvis (Fig. 2). Pelvic girdle

![Correct vs Wrong](image)

**The athlete should be able to stand upright on the supporting limb, one legged, for 30 seconds without tilting his body position for balance; or on command stand up onto his tip toes 10 times without shifting body position**

Fig. 2. Functional Romberg Test. (Courtesy of M.D. Dollard, DPM, Sterling, VA.)
muscular strength is essential to maintain proper axial posture and stability for avoidance of spinal and lower extremity pathologic injury. Preseason programs should be designed to strengthen the hip flexors and extensors, the lateral stabilizers, the abdominal muscles, and the hamstring muscles about the pelvic girdle to ensure axial pelvic stability (Fig. 3).

150% Body Strength Rule

Because sports loads may amplify body weight strain onto the axial skeleton between 2.5 and 4 times normal body weight, an athlete must be able to squat press at minimum of 150% of his or her body weight before participating in any type of ballistic activity, such as explosive jumping sports or fitness aerobics. Tests to evaluate such strength levels may include squat presses of weights at loads of 150% of the athlete’s body weight with free-weight or squat-press machines. Not until the athlete is able to readily squat press 150% of his or her body weight should the youth be allowed to participate in competitive sports (Fig. 4).

Agility Index for neuromuscular reflex reaction

Many sports entail a competitor’s agility to react, twist the torso, shift position laterally, and execute contorted movements. Agility testing is essential in

Fig. 3. Strengthening the pelvic girdle muscle. (Courtesy of M.D. Dollard, DPM, Sterling, VA.)
Since sports may induce a load > 2.5x body weight, then an Athlete or Fitness participant must be able to squat press 150% of their body weight before participating in any type of ballistic activity such as Aerobics or Explosive Sports.

Fig. 4. Minimum body strength rule. (Courtesy of M.D. Dollard, DPM, Sterling, VA.)

Evaluating neuromuscular reflex reactivity in the athlete. The Agility Index drill is designed by placing several construction cones aligned in a zigzag pattern stretched across a 30-yd distance. The athlete is then asked to run and cut in and around the cones in a figure-of-eight weaving pattern within a specific period of time while performing specific agility maneuvers at each station along the way (Fig. 5). Any evidence of stumbling or difficulty in executing these maneuvers...
should raise suspicion of immaturity in neuromuscular agility. The athlete may need to undergo specialized agility skills training before being placed in competitive sports events.

**Designing preconditioning programs**

*Acclimatization: preconditioning*

Clinicians need to be aware of the concept of acclimatization as it relates to preconditioning programs. In a more basic sense, acclimatization understands that a body that has been relatively inactive for a period of time needs to adapt to a new level of exercise intensity, duration, and frequency. There are four basic concepts involved in the design of a preconditioning program: strength training, flexibility training, agility training, and performance training. Peak performance training routines are designed to accelerate the body’s cyclic ability to cope with the rigors of sports by peaking midseason to prevent the body from experiencing general fatigue and body system failure. Performance training areas are discussed first.

*Preconditioning for performance*

*Performance training*  
Performance has a mixed definition depending on the motivations of the athletes and their supporters. Goals can vary from physical achievement in skills performance to win-loss records in youth sports. Regardless, the clinician should be aware that performance in training circles is often broken down into three areas: sports-specific skills, technique execution, and cyclic peaking.

*Sports-specific skills.* Individual sports naturally have greater demands on specific muscle groups. The football quarterback designs a training routine emphasizing the upper torso for throwing. The track and field hurdler is more apt to concentrate on lower extremity development. It is beyond the scope of this article to outline the training routine of each specific sport. For those interested, however, we would highly recommend becoming involved with such organizations as the National Strength and Conditioning Association, National Athletic Trainers Association, and American College of Sports Medicine and their publications, which report on specific sports, as well as their training routines to achieve peak performance. These programs outline preseason and off-season weight training and conditioning drills. These individual training programs target the various muscle groups that are specific to athletic function in sport.

*Sports technique execution: improper technique, asymmetry, and repetition.*  
*Improper technique.* Valuable information is gained by monitoring the technical execution of various training routines in sport. Clinicians are often con-
fronted with the long distance runner who displays improper technique with excessive twisting pelvic sway or extended knee strike. Poor running techniques can induce problems such as piriformis sciatic nerve entrapment syndrome in which the sciatic nerve is sandwiched between the pyriformis and gemellus muscles in the pelvic region, causing radiating pain (paresthesias) into the leg [8].

Asymmetric routines. Few coaches are aware of the potential consequences of asymmetry in their designed training regimens. A commonplace example is with competitive weightlifting, in which a “clean and jerk maneuver” explosively lifts heavy barbell weights over weightlifter’s head [9]. This maneuver is often performed with one leg repetitively thrusting forward and the other leg thrusting backward for balance. By failing to alternate both legs to ensure symmetric training, individual muscle groups become overtrained. These overtrained muscle groups overpower their antagonist. We have seen severe functional scoliosis develop in weightlifters as a result. A practitioner must be aware of any asymmetry involved in the athlete’s training routine to best judge how and why injuries are occurring that may differ from one limb to the other. In another example, soccer players experience a different set of injuries in their planted foot as opposed to their kicking foot. Soccer preseason drills need to challenge both limbs equally.

Repetitious maneuvers. Repetitive motion creates fatigue stress. Ballet maneuvers represent such repetitive motion injuries. The repetitive extremes of inversion and eversion rolling of the foot, known as “sickling,” raises the body up to the point position on the toes. This action constantly jams the os trigonum bones behind the ankle and fatigues the flexor hallucis longus tendons. Fibrous polyp formation or tears in the flexor hallucis longus may plague the ballet dancer. Differentiating between a fracture of the os trigonum versus polyps within the flexor hallucis longus is often difficult even with sophisticated diagnostic tests, such as MRI [10–12].

Performance peaking: Cyclic periodization and supercompensation

A major goal of this review is to provide the clinician with an understanding of the principles of cyclic training to enhance peak performance throughout the athletic season. Periodization is best defined as a system for applied cyclic variances in training intensity and workload throughout the competitive season to acclimate the athlete’s body to reach higher levels of performance in avoidance of fatigue or injury [13,14]. This step-graded approach supercompensates the athlete to achieve higher levels of performance and endurance [15]. In general, the Cyclic 3:1 Day Rule is instituted by trainers and coaches to accomplish this cyclic task. Simply explained, athletic training is progressively intensified over 3 days and then followed immediately by a mandatory 1 day of rest. In general, exercise physiologists profess that protein synthesis needed for recovery occurs not during exercise periods but during rest periods. Exercise periods break
down protein tissue. Rest periods are absolutely necessary for protein tissue recovery [16].

**Micropeaking**

Micropeaking is defined as a period of four daily practice sessions in which the athlete’s body is gradually stressed to higher levels of performance in three of the four sessions. The fourth session becomes a vital period of rest. After the rest session is completed, a new cycle of training starts. The body is now physiologically able to adapt and accommodate to higher workloads placed on it by super-compensating to a higher level of performance (Fig. 6). At the critical start point of a new four-session cycle, a new progressively higher load or intensity is placed on the body. Because recovery is allowed during the preceding rest period, the body is able to rebound to a higher level of stress management. Typically, in a 1-week scenario, as workloads are progressively increased to an established stress set point, the body fatigues by the end of the third day. Determining that set point is discussed in a later section. For now, programs for strength and weight training establish the set point as a measure matched against a weight index, the One Repetition Max (IRM). The IRM refers to the maximum weight that a person can lift for a total of 10 repetitions, reaching a “max-out” fatigue point. The initial IRM is set before any starting point in a cyclic training program. After the rest session, a new IRM is then reset to a progressively higher maximum weight level for the next cycle of weight training [17]. This graded training principle is called progressive resistance exercise (PRE). Alternately, if the goal is to increase endurance levels, the 10% Endurance Rule applies. This set point is indexed by

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**Fig. 6. Supercompensation. (Adapted from McFarlane B. Dynamics of adaptation: supercompensation. NSCA Journal 1985;7(3):44–5, with permission.)**
no greater than a 10% increase in duration and intensity of exercise over any week’s time [18].

**Macropeaking**

Macropeaking is best defined as a monthly cycle of several week-long sessions graduated over the course of the entire season, peaking the athlete three quarters of the way through the season to maximize his performance. The Cyclic 3:1 Day Rule applies here as well. Taking the same rule as with 1 week of microloads and applying the rule to the 4 weeks on a monthly scale, athletes may be able to avoid common overuse injuries. By the fourth month of the competitive season, general body fatigue may begin to overshadow performance. With macropeaking principles, workout sessions tend to increase in their intensity and load over 3 weeks of workouts followed by 1 week of low-level activity for rest and rebound (Fig. 7). Otherwise, it is well known that overuse injuries appear at roughly the third week after initiating a poorly developed noncyclic sports training program. At this point, the body is at its most vulnerable point from fatigue strain on skeletal bone remodeling. Many participants in recreational or fitness activities, such as aerobic dance or organized sports, often break down physically at this 3-week point by failing to adhere to these cyclic principles of training. Our experience with high incidences of injuries 3 weeks into a typical health club aerobic dance program testifies to the high occurrence of metatarsal stress fractures, tibial stress fractures, and other overuse injuries at this point.

![Cycling the intensity of training routine to reach maximum performance Mid Season, before fatigue sets in, followed by an off-season rest period](image)

**Principle:** After 3 weeks of training an easy 4th week is needed for super-compensation or else overuse injury ensues

*Fig. 7. Performance peaking. (Adapted from McFarlane B. Dynamics of adaptation: supercompensation. NSCA Journal 1985;7(3):44–5, with permission.)*
Therefore, cyclic training best requires a mandatory session of rest after three sessions of activity on a weekly, monthly, and season-long schedule.

**Preconditioning for flexibility, agility, and strength**

**Flexibility training**

As discussed previously, physiologic hazards associated with prepubescent Tanner stage III youth are caused by sudden tendon tightness about joints induced by long bone growth spurts. Flexibility programs are essential at this youth level. Adapting the body's response to enhance the myotatic reflex and Golgi tendon organ (GTO) systems within muscle and tendon is vital to flexibility standards. The myotatic reflex response invokes an intramuscular contraction to avoid tearing from overstretching. The GTO systems are a complex of intermuscular reflexes that balance relaxation of antagonist muscle groups with the agonist muscle. This allows the agonist muscle to move a joint through its full range of motion unimpeded. This concept is referred to as reciprocal inhibition. Without precise coordination of these two muscle reflexes, shock absorption at joints is compromised. Athletic performances are hindered, and bone fracture syndromes are induced. Three different types of techniques are available to improve flexibility: static and passive stretches, proprioceptive neuromuscular facilitation (PNF) buddy stretches, and ballistic-bouncing stretches [19]. Immediately before any stretching drill, an athlete should warm up his muscle groups with a prestretch brisk walk or light jog.

Static stretch techniques are the preferred method to increase flexibility in youth groups. An individual muscle is passively stretched by the athlete to a maximum length for 30 seconds, which is repeated for three to five sets. These stretch drills are easily understandable, readily demonstrable, and easily reproducible by the youth athlete. The key muscle groups for general body stretching should include the lumbar torso, the Achilles tendons, the hamstrings tendons, the lateral hip iliobial band tendons, and the iliopsoas muscle group (Fig. 8). Youth athletes at Tanner stages I, II, and III respond well to static stretch techniques.

Proprioceptive neuromuscular facilitation (PNF) stretches involve a buddy system in which a counterforce is placed against a contracting muscle to invoke reciprocal relaxation in its antagonist muscle [20]. A counterforce is held by a buddy for 6 seconds against the desired agonist muscle (eg, hamstring) while that muscle is voluntarily contracted. This eventually fatigues the myotatic reflex. The muscle contraction is then relaxed, and the buddy passively stretches the fatigued agonist muscle-tendon unit while the antagonist muscle (eg, quadriceps) is voluntarily contracted for 3 seconds to invoke a GTO response by the antagonist, which reciprocally causes relaxation in the stretched agonist, the hamstring. A far greater outstretch of the agonist hamstring can be executed (Fig. 9). The athlete must have a well-developed nervous system to take advantage of this PNF technique. Because of the complexity in the execution of PNF techniques, they are usually reserved for mature Tanner stage IV athletes.
Ballistic stretches are an extraordinarily delicate series of controlled bouncing drills that rapidly invoke myotatic and GTO function with functional agility [19]. Because of their powerful effect, requiring accurate balance, they are reserved for use in supervised elite ballistic sport programs, such as volleyball, basketball, or sprinting. These active agility stretches are often used within preparatory drills known as plyometric reaction drills for sports requiring explosive power. In a more basic form, these plyometric agility drills can be modified to a less intense degree for use in a precondition program to awaken senescent muscles, increase neuromuscular recruitment, and enhance reflex reactivity.

**Agility training: plyometric ballistic exercise preconditioning**

Plyometric training is a controlled system for converting kinetic energy into explosive power by fine-tuning coordination between myotatic and GTO reflex systems, thus enhancing the body’s dynamic proprioceptive abilities. This is accomplished through a series of jumping drills. The basic drill in plyometric conditioning uses rebounding jumps into a series of agility drills (Fig. 10) [4,16,21]. Great explosive power is produced when the neuromuscular proprioception reflexes are challenged by experiencing a controlled sudden eccentric stretch followed by a rebounding concentric contraction. Our clinic has designed a plyometric circuit training system based on stations positioned around a running track (Fig. 11) [22]. At each circuit station along the track, the athlete is
expected to perform any of a series of the following drills within a hopscotch grid: running in-place, jump rope, chopping drills, carioca scissoring, single leg jumps, double leg jumps, hopscotch forward, hopscotch zigzags, and double hops. Depending on the athlete’s Tanner stage, low-level weights may be added progressively to overload the muscles and supercompensate the athlete to higher performance levels (Fig. 12).

**Strength training preconditioning**

**Basic principles of weight training**

The progressive overload principle holds that a muscle must be progressively challenged with a greater resistance or load to improve strength or endurance.
Strength training assists the body in maintaining postural integrity (endurance) or work output performance (strength). Muscle physiology, fiber typing, or the aerobic and/or anaerobic demands of an individual sport dictate training approaches with weights [23,24].

Explosive power sports usually call on fast-twitch type IIb muscle fibers, which function for high work force for a short duration of activity. These fiber types have great tension potential but are anaerobically inefficient in energy consumption. Training these muscles usually focuses on strength principles aimed at quickly lifting heavy weights through three sets with a low number of
repetitions (eg, <9 repetitions). Endurance sports, such as cross country, typically call on slow-twitch type I fibers with activity of long duration with high aerobic efficiency. Training these muscles focuses on endurance principles aimed at lifting low weights through three sets with a high number of repetitions (eg, >15 repetitions). General maintenance with weight training often must combine endurance and strength principles, because postural muscles of balance in the pelvis and spine tend to be “endurance”-oriented slow-twitch fibers responsible for holding axial balance position over long periods of time. Performance muscles of power in the extremities tend to be “strength”-oriented fast-twitch fibers responsible for quick forceful actions.

Whether for strength or endurance training, the standard index for the amount of weight used as a training tool is based on the one repetition maximum (1RM) set point. Now that the 1RM is understood, the typical weightlifting schedule for endurance or strength training is designed over the course of sessions according to the 3:1 rule. Weight loads are gradually increased until muscular contractions fatigue at the max-out point for any particular set of muscles. The following schedule is typical:

- **Strength muscle training (type II fibers [eg, quadriceps]):** weight at 80% to 100% 1RM (three sets with 8–9 repetitions)
- **Endurance muscle training (type I fibers [eg, abdominals]):** weight at 60% 1RM (three to four sets with 15 repetitions)

Successful weight training seeks to challenge a muscle’s tension potential throughout its entire fiber length and its full range of motion. Weight training through concentric contractions (ie, shortening tension) or eccentric contractions (ie, lengthening tension) may differ depending on the actual equipment in use. This specific discussion is beyond the scope of this article. Interested readers may seek further information on the tension-curve relationship brought about by weight training equipment using various resistance techniques: (1) isometric resistance (ie, same length with increased tension), (2) isotonic variable resistance (ie, same tension with variable resistance [eg, Nautilus with free weights]), or (3) isokinetic resistance (ie, variable speed with variable resistance [eg, Cybex with machines]).

**Weight training and children**

Weight training in children is a controversial issue. An inadequate testosterone level is often cited as the reason why weightlifting for strength gain has little value for fitness or athletic conditioning in prepubescent children [25] Some views hold that children cannot benefit from any form of weight training until they achieve Tanner stage III. Sewall and Micheli [26] studied weight training in children in Tanner stages I and II, reporting significant gains in muscular strength in response to progressive muscle training. HeiJa found that high-school athletes participating in a comprehensive weight training program had approximately one third fewer injuries. The American Orthopedic Society for
Sports Medicine has recommended that weight training for prepubescent children follow these guidelines: (1) no maximal 1RM lifting, (2) limit weight training to two to three times a week at 20 to 30 minutes each session, and (3) no more than three sets of lifting with six to nine repetitions per set. In prepubescent Tanner stage II children, technique training is best emphasized over strength training to improve neuromuscular development and recruitment. In later Tanner stages III and IV (usually in children aged 14–17 years), the principles of progressive resistance exercise can be acceptably individualized per athlete and specific sport needs.

Summary

Preseason preconditioning can be accomplished well over a 4-week period with a mandatory period of rest as we have discussed. Athletic participation must be guided by a gradual increase of skills performance in the child assessed after a responsible preconditioning program applying physiologic parameters as outlined. Clearly, designing a preconditioning program is a dynamic process when accounting for all the variables in training discussed so far. Despite the physiologic demands of sport and training, we still need to acknowledge the psychologic maturity and welfare of the child so as to ensure that the sport environment is a wholesome and emotionally rewarding experience.

References

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For over 20 years, Podiatrist, Dr. Mark Dollard, has sub-specialized in the sports-medicine needs of professional, amateur, and elite athletes. He has served as the National Sports-medicine Chairman for the Amateur Athletic Union, Inc., the largest volunteer multi-sport amateur organization in the Olympic family. His duties required overview of medical policy protecting over 350,000 athletes and coaches in 23 team and individual sports. He served as chief medical protocol officer for two major AAU Junior Olympic Games Festivals hosting 10,000 athletes each.

His dedication to sports safety earned him a seventeen year appointment to the National Alliance of Youth Sports and the National Youth Sports Coaches Association, (NAYS/NYSC), an organization of over 250,000 coaches. The association’s mission is to advocate for the physical safety, and both the psychological and social welfare of athletes in youth sports programs. During this time, NYSC trained and certified over two million coaches in sports safety.

Dr. Dollard was named by “Podiatry Management” magazine in 1997 as one of the top six “Movers and Shakers” in Podiatric Sports-medicine.