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A Literature Review of Strengthening and Injury Prevention Techniques as Related to High School Athletes

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A LITERATURE REVIEW OF STRENGTHENING AND INJURY PREVENTION
TECHNIQUES AS RELATED TO HIGH SCHOOL ATHLETES

by

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Bachelor of Science in Physical Therapy
University of North Dakota, 1993

An Independent Study
Submitted to the Graduate Faculty of the
Department of Physical Therapy
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in partial fulfillment of the requirements
for the degree of
Master of Physical Therapy

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1994
This Independent Study, submitted by Matthew N. Miller in partial fulfillment of the requirements for the degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

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ABSTRACT

In the U.S. an estimated 20-25 million youths participate in high school athletics yearly. Of these, nearly 30% will be forced to miss part or all of the season due to injury. It has been speculated that through proper training, many of the injuries seen may be reduced or eliminated. However, most coaches do not have an extensive anatomical and physiological background to provide athletes with these correct training techniques. Although athletic trainers have expertise in this area, they are only employed in approximately 10% of the high school systems in the U.S.

Much of the research to date on this subject is in regard to post-injury rehabilitation. It has been speculated that many athletic injuries may be prevented by employing similar techniques as those utilized with injury rehabilitation. Physical therapists are coming into contact more frequently with the athletic population. Teaching proper strengthening and conditioning techniques specifically for the prevention of injury is a component of physical therapy practice. However, no specific guidelines appear to be available regarding the effects of training of an athlete for strengthening, tied together with the prevention of injury. Therefore, it will be beneficial if resource materials...
are prepared to assist physical therapists in providing coaches and athletes with this information.

The purpose of this study is to provide: (a) a basic insight into the current theories behind strength training and the benefits on the muscular system, (b) information for coaches and trainers about effective training principles that will strengthen athletes, and (c) additional information regarding the prevention of injuries due to overtraining, muscle imbalances, inflexibilities, and fatigue.
CHAPTER 1
INTRODUCTION

According to Zito, the ideal treatment is prevention. Therefore, responsible treatment begins with strategies to prevent injury. In the United States, it is estimated that over 20 million children between the ages of 6-16 participate in recreational youth sports programs yearly. It is further estimated that another 30 million participate in less organized or civil activities. Many of these young athletes are involved in programs that involve year-round practice, competition, and conditioning, either in single or in multiple overlapping sports. Of these participants, as many as 30% may be forced to miss part of the season due to injury, and 10% may have to sit out the rest of the season and a possible athletic career due to injury.

When athletes are injured, they are forced to give up or cut down their sporting activities. Thus, they are unable to pursue some or all of their goals within, as well as outside, athletics. Other factors that need to be considered are: (a) if the injury is serious enough, the athlete will be forced to miss an indefinite amount of school time and (b) the athlete's family will undoubtedly be faced with the financial burden of numerous medical bills. If the consequence of an injury is shifted from the athlete onto the athletic population of the school,
a team within a school with a large number of student athletes may be able to absorb the loss. However, in a small school, the loss of one player may be the difference between a winning and losing season.

To date, injury prevention information regarding athletics has been primarily directed towards the college and professional athletic population. The information concerning high school athletic injury prevention is, more often than not, focused on equipment, safety, and the importance of preparticipation examinations. Several authors, however, have stated the need that more specific research is needed in the area of training techniques for the prevention of athletic injuries.

The literature available that is directly related to athletic injury prevention using proper strengthening techniques and training procedures is very limited. However, there are volumes of available material written and designed specifically for the rehabilitation of an athlete post-injury or post-surgery. According to McKeag, prevention of injuries through properly designed training techniques will be a major issue for research within the next decade. Furthermore, preliminary studies have shown that proper lifting and training habits can reduce the risk of injury. Currently, though, it should be recognized that, in many instances, it is assumed that training techniques designed to increase strength will also directly decrease the occurrence of athletic injury. As well, it is commonly believed that a highly strengthened athlete is capable of handling the stresses put on his or her body better than a poorly strengthened
athlete. Even the most highly trained athlete may be at a predisposition to injury if he or she has been taught improper training/strengthening techniques.

Unfortunately, in many instances, athletic coaches at the high school level may not possess enough anatomical and physiological background to recognize the warning signs of poor training techniques that predispose their athletes to overuse injuries. In 1991, it was established that certified athletic trainers were only employed in approximately 10-20% of the nation’s high school systems. Zito has commented that insurance companies resist paying medical bills for athletic trainers providing service to school sports, and he reports that the lack of athletic trainers in high school sports is a major problem.

Because coaches often provide the only supervision an athlete has during training, they must be educated on how to recognize the signs of improper training techniques and how to prevent the occurrence of athletic injuries caused by such techniques. Correct and directed training techniques need to be developed to keep the athletes strong, healthy, and at their full potential through the school year. These things have to be taught under the watchful eyes of the athletes' coaches and trainers. Well-trained coaches are rare in the high school age group, and because of current economic constraints, this is likely to worsen.

Taking into consideration the few factors mentioned above that contribute to the occurrence of athletic injury, as well as the many others not mentioned, the purpose of this study is: (a) to give a brief insight into the current theories
behind strength training and the benefits of strength training on the muscular system, (b) information for coaches and trainers about effective training principles that will strengthen athletes, and (c) additional information regarding the prevention of injuries due to overtraining, muscle imbalances, inflexibilities and fatigue.

Furthermore, and very importantly, it should be remembered that proper training and conditioning is only one means of athletic injury prevention. This paper will not attempt to cover all of the other aspects. Examples of other factors include: protective equipment, playing conditions, nutrition, and sport psychology.
CHAPTER 2
INJURY STATISTICS

Regardless of who is training the athlete and the steps taken to reduce injury, injuries will undoubtedly always occur. Injuries are, and always will be, a part of athletics. In the wide ranging field of athletic competition, the potential for injury occurs within each sport. Yearly statistics are recorded that quantify the numbers of injuries that occur. However, due to the many different baseline definitions of the word "injury" that are used, it is difficult to determine just how many injuries occur per sport per year and why.

Before an explanation can be made about specific training techniques to reduce the chance of an athletic injury, there has to be an identifiable baseline of information to exactly explain what is an injury. That is, a definition and a proper explanation of an injury has to be determined before methods are developed to alleviate them. Several authors have attempted to establish such a guideline, and all involve, to a degree, some sort of discrepancy regarding the definition of the word "injury." A general definition, according to Van Mechelen, is that a "sports injury" is a collective name for all types of damage that can occur in relation to sporting activities. Some studies report sport injuries as those sustained during sporting activities where an insurance claim
was filed. In other studies, the definition is confined to injuries treated at a hospital or other medical facility.  

The results of the various studies performed are not comparable. If sports injuries are recorded through the medical channels, a fairly large percentage of serious, predominantly acute injuries will be observed, and less serious and/or overuse injuries will not be recorded. If this type of definition is used, only a small selection of injuries will be revealed. A study performed in 1990 using a broad based definition of sports injuries and an athlete's self-report of all injuries found that 43\% of all injuries were found to be medically treated.

Taking all other definitions into consideration, the National Athletic Injury Registration System (NAIRS) has defined an injury in this way. "The reportable injury is one that limits athletic participation for at least the day after the day of onset." NAIRS classified injuries, according to the length of incapacitation, into "minor" (1 to 7 days), "moderately serious" (8 to 21 days), and "serious" (over 21 days or permanent damage).

An example of an even more extensive definition is one proposed by the Council of Europe, in which a sports injury is defined as any injury that occurs as a result of participation in a sporting activity with one or more of the following consequences: (a) a reduction in the amount or level of sports activity, (b) a need for medical advice or treatment, and (c) adverse social or economic effects. However, within this paper, for the purpose of simplicity and
understanding, an explanation of injury will be based on the literature presented and defined by the respective topic in each section.

Regardless of the definition used to determine what is an injury, the fact still remains that many injuries occur where they could have been prevented. Smart training and conditioning techniques, as mentioned earlier, are only part of the entire scheme of athletic training that attempts to decrease the occurrence of athletic injuries.

According to Halpern,\textsuperscript{25} in a 1980 to 1981 study of children and adolescents in the state of Massachusetts, one out of every 14 youths brought to the emergency room was due to a sporting accident. Seventeen percent of those injuries resulted in hospitalization. The largest percentage of these injuries were football related (20\%). Furthermore, according to Thompson et al,\textsuperscript{26} the overall likelihood that a player has sustained a football-related injury ranged between 11\% to 81\%. This represents, nationally, a minimum of 165,000 of young men sustaining football injuries each year. This number is more likely to be between 300,000 to 1,215,000.

In a study performed by Garrick,\textsuperscript{27} the greatest percentage of injuries that occurred over a two-year period in four urban high schools per sporting activity were in football (81/100 participants) and wrestling (75/100 participants). The lowest occurrences of injury were in men's tennis (3/100) and men's swimming (1/100) (Table 1). By viewing these statistics, it is obvious that athletic injuries occur regardless of event. Furthermore, the greatest number of injuries that
occur in football players were in the lower extremities.\textsuperscript{25} Approximately 40\% of all football injuries were sprains and strains. The single most common overall anatomical location for injury was the knee (25\%). Furthermore, the knee was the most commonly injured site in elite volleyball players.\textsuperscript{28}

A study by Baxter et al\textsuperscript{29} concluded that the greatest number of injuries occurred in football (67\%), and the lowest incidence was in swimming (37\%). Within this study, most of the injuries (70\%) were acute and minor in nature, requiring the athlete to miss 20 + 13 days of activity.

Because contact sports (like football and soccer) place athletes in positions where injury is more likely to occur than in non-contact events (like swimming or tennis), the percentage of injuries in contact sports vs. non-contact sports is much higher. There are also higher percentages of certain types of injuries that occur within specific sports. As mentioned earlier, volleyball as well as football players have a high tendency for knee injuries.\textsuperscript{25,28,30,31} This tendency for injury is, in part, due to a combination of factors including: (a) the playing surface, (b) running and jumping style, and (c) type of shoe worn.

Baseball players and swimmers commonly develop a high percentage of shoulder injuries that are specific to their sport. The shoulder is extremely vulnerable to injury when repetitive, high-energy forces are placed on it during sporting activities.\textsuperscript{9} When these stresses are applied at a rate that exceeds that of tissue repair, progressive damage to the shoulder's stabilizing structures can occur. With continued throwing or use of the same stroke, the static restraints
(the inherent shoulder joint ligaments) become progressively stretched, thus allowing for anterior glenohumeral subluxation.16

There are many more statistics available that quantifiably show the percentages of injuries due to athletics. For further information regarding injury percentages, the reader is advised to refer to table one in the appendix.
CHAPTER 3
STRENGTH TRAINING

There has been some question as to whether strength training in young adults is safe or advisable. Through research, it has been found that strength training in prepubescent athletes is safe when performed under supervision.\textsuperscript{32,33} The results have shown that supervised concentric strength training has a very low rate of injury incidence. It has also been found that concentric training does not adversely affect bone, muscle, or epiphyses, as well as growth, development, or flexibility.\textsuperscript{33} To fully understand the rationale behind proper training, an historical overview of strength training should be reviewed. This will serve as a foundation to build a well designed strength training program.

Lifting of heavy weights to increase strength and power has been observed for centuries. The dumbell is of ancient origin, and the barbell was first developed at the beginning of this century and soon became the standard for strength training.\textsuperscript{34} The first exercise machine was developed in the 1870s and consisted of a system of levers, wheels, and weights.\textsuperscript{12}

Prior to the 1940s, strength training was very non-specific and there was no true scientific or physiologic basis to explain the benefits of strengthening. It was not until World War II that a scientific basis for strength training was
developed. This development is greatly attributed to Dr. Thomas DeLorme. He developed a strengthening program which he initially called Heavy Resistance Exercise. In 1948, he revised his method of Heavy Resistance Exercise and adopted the name Progressive Resistance Exercise (PRE). Since then, additional studies have substantiated and expanded upon his results. As well, descriptions of other strength training techniques further explained the benefits of different methods of strength training and their effects on the musculoskeletal system.

Prior to the 1950s, muscular strength training was used predominantly by bodybuilders, competitive weight lifters, and some wrestlers. During the 1950s, the world of athletics and athletic participation became more and more competitive. As a result, research was conducted to show the benefits of specific training principles to increase athletic performance. Increasing an athlete's strength and power was the basis of training until the function of skeletal muscle was properly understood.

In 1951, DeLorme documented on the overload principle of weight training. This developed a foundation for strength training and weight resistance training techniques. This principle stated that strength training involves a low number of repetitions with a high load of resistance. A muscle's response to this increased activity or external resistance is the production of an internal counter force sufficient enough to overcome the external force. The more resistance applied to the muscular system, the more adapted and
stronger the muscle becomes. In experiments,\textsuperscript{4} strength gains were made faster and reached higher levels as the intensity of the exercises were increased. In 1954, Hettinger and Muller\textsuperscript{7} introduced the benefits of isometric training, which provided an additional means of strength training.

Isometric strengthening involves resistance without joint movement, such as pushing or pulling against a fixed object. An example of an isometric contraction is an exercise called the wall sit. The athlete assumes a position of sitting against a wall with his or her hips and knees flexed to 90 degrees. In this position, there is an isometric co-contraction of the quadriceps and the hamstring muscle groups. A maximal isometric contraction, lasting a duration of more than one minute, may be deleterious to the musculoskeletal system.\textsuperscript{11} After one minute, the blood flow to the muscle is cut off due to the high contractile forces applied by the muscle fibers. The muscle becomes ischemic and, therefore, is more prone to fatigue. Ischemia in muscle has been found to be one of the causes of post exercise soreness.\textsuperscript{5} Another fault of isometric training is that the muscle will only be strengthened in that particular position, with little strength carry-over in other positions. If the quadriceps are isometrically strengthened at 90 degrees, they will be strongest at 90 degrees, with little carry-over to 180 degrees.\textsuperscript{15}

In opposition to isometric contractions, isotonic contractions occur during limb motion. Isotonic contractions happen either as the muscle is shortening (concentric) or as it is lengthening under tension (eccentric). An example of
both types of contractions can be easily seen when performing a biceps curl against resistance. As the forearm is brought closer to the body, the biceps are contracting concentrically, and the muscle is shortening. As the weight is returned to the starting position (full arm extension), the biceps undergo an eccentric contraction. That is, they are lengthening under tension.

In 1967, Hislop and Perrine introduced a third type of resistance exercise called isokinetic strengthening. In this type of exercise, the rate at which the contraction is allowed to occur is constant. Regardless of the force used, the speed of movement through the range of motion cannot be altered. Isokinetic strength training attempts to combine the best features of isometric and isotonic training to provide maximal muscular loading at a preset speed, while the muscle produces a maximal force through the full range of motion. Isokinetic strength training equipment can be used isometrically, concentrically, or eccentrically.

In recent years, there has been great debate as to which category of strengthening exercises is more beneficial; isometric, concentric, or eccentric. The following results have been documented in research by Anderson et al. Some authors found significant correlations between isometric strength and functional performance, while others found no significant correlations. Several authors found that combinations of measured isometric and isotonic strength correlated most highly with functional performance. Significant positive
correlations were found between strength assessed isokinetically and functional performance, while others found no such correlations.

It has been documented through research that eccentric muscle contractions are significantly different from concentric muscle contractions. With the same resistance, eccentric contractions consume less oxygen, require smaller amounts of adenosine triphosphate, and possibly involve fewer motor units. Physiologically, the current belief regarding this phenomenon suggests that the sarcomere cross bridges develop greater force when they resist lengthening rather than shortening under load. 

Many skeletal muscles can support twice as much force eccentrically as they can concentrically. As the velocity of limb movement increases, eccentric tension potential increases, and concentric tension potential decreases. However, a negative aspect of eccentric muscular strengthening is that muscle pain and tenderness develop preferentially after eccentric training. Furthermore, eccentric muscle contractions are associated with evidenced ultrastructural indications of muscle damage to a much greater extent than concentric muscular contractions.

Many studies have found that both eccentric and concentric training techniques stimulate strength gains in human skeletal muscle. However, it is not clear whether one method is more effective than the other.

As mentioned earlier, muscle training can be isometric, concentric, or eccentric. Concentric and eccentric are the most commonly used training
methods in injury prevention. Eccentric action of muscles is common to many preload situations in sports. It should be remembered that the normal functions of muscles during any type of athletic event are not solely isometric, concentric, or eccentric, but a combination of the three. The muscles perform in a stretch-shortening fashion, in which the stretch (eccentric contraction) precedes the shortening (concentric) action. Furthermore, research performed by Tomberlin and associates, have clinical implications because eccentric training techniques are commonly overlooked in strength training programs. As mentioned, eccentric training can produce higher tensions in muscle than concentric contractions and, therefore, may provide a more effective stimulus for improved muscular performance.

Regardless of the type of strength training utilized, a basic understanding of what is happening anatomically and physiologically to the muscles, tendons, and ligaments must be evaluated. In the following pages, the basic physiological factors associated with strength training and its effects on anatomical structures will be reviewed. A discussion of how these structures may aid in the prevention of athletic injury through inherent protective mechanisms and adaptability will also be reviewed.

According to research, resistance training has promoted growth and/or increases in the strength of ligaments, tendons, tendon to bone, and ligament to bone junction strength, as well as joint cartilage and the connective tissue sheaths within muscle. Strengthening of the muscular system has its obvious
effects of increased mass and hypertrophy and tensile strength.\textsuperscript{38} However, an often overlooked benefit of muscular resistance training is the advantage of injury prevention as a result of the increased strength in ligaments and tendons.\textsuperscript{4}

It is well documented that various types of resistance training are effective in increasing muscular strength.\textsuperscript{2,3,5,7,11,12,36,39} Muscle enlargement has also been produced through frequent bouts of muscle contraction against a high resistance, such as weight training. As a result, muscle fibers become thicker and the muscle therefore grows by hypertrophy (an increase in cell size). However, there has been some controversy in the past years regarding whether adult skeletal muscles could only grow by hypertrophy rather than hyperplasia (an increase in cell number).\textsuperscript{39,40}

The role of muscles in protecting bone from bending was emphasized in an article by Radin.\textsuperscript{7} Muscles are believed to be the major factor reducing bending stress in bone. Muscles are composed of different fibers and are mainly classified as either Type I (red, slow twitch) fibers or Type II (white, fast twitch). Type I muscle fibers are primarily aerobic in nature and have a significant blood supply. This type of fiber does not fatigue easily. Type II fibers, on the other hand, have a decreased blood supply as opposed to the Type I fibers and are considered anaerobic in nature.\textsuperscript{11}

It appears that people have a genetic tendency to have either a large number of either Type I or Type II fibers, depending on their body type and
composition. Long distance runners and other athletes who require an endurance base, have more efficient Type I fibers, whereas athletes who participate in short duration high intensity events, like weight lifting, have a predominance of Type II fibers.

Type I muscle fibers are the major components involved in reducing bending stress in bone. Further, it is this type of contraction, as controlled through a reflex arc, that probably protects the bones from the fracture forces generated by non-contact athletic activity. It has been postulated that this reflex arc is initiated by ligament and joint receptors and influences muscular activity.

Muscles which function to alternate peak dynamic forces through a reflex loop are referred to by Radin as being reflexurally controlled. For example, upon landing from a jump, a person lands with his or her hips and knees bent and on the balls of his or her feet. The muscles which span these joints are, in advance to landing, slightly contracted and ready to absorb the energy produced by the jump. Upon landing, as the joints are moved, the hips, knees, and ankles are straightened out. The slightly contracted muscles that span these joints are stretched upon landing, producing an eccentric contraction. This protective muscle action controls the movements of the joints that are holding them in place.

Under control of a reflex loop, as these muscles are stretched, their contraction is gradually released, so the musculature will not be torn. This stretching of muscles under tension uses the muscles as springs; i.e., they
absorb energy. This reflexural readiness is important to protect the joints and bones. It has been experimentally demonstrated that in humans, unexpected falls of less than 25 mm are felt as a jolt, whereas jumps from higher levels can be handled with an uncomfortable landing.\(^7\)

Continuing with the importance of reflex loops, it has been well established that proper training of the quadriceps and hamstrings can reduce instability caused by a cruciate ligament section rupture.\(^{41-43}\) During a maximal quadriceps contraction, a synergistic muscle activation is initiated by a rapid reflex arc between the anterior cruciate ligament (ACL) and the hamstrings, which act together to limit anterior tibial translation on the femur.\(^{43}\) Without this reflex arc, a maximal contraction of the quadriceps could initiate anterior translation of the tibia on the femur, and thus stress the ACL. The hamstrings are activated in this sense as a protective mechanism and serve in addition to the ACL in prevention of anterior tibial translation.

In a study conducted by Solomonow et al.,\(^{44}\) the antagonist coactivation patterns of the hamstrings and quadriceps of non-athletes, athletes, and athletes who routinely exercised their hamstrings were observed. The study substantiated that the hamstring coactivation patterns collected from athletes who did not exercise the hamstrings were substantially depressed compared to the hamstring coactivation pattern of the non-athletes and athletes who routinely exercised their hamstrings. In other words, athletes who routinely exercised their hamstrings had a significantly increased reaction time to stress
applied at the knee joint, as opposed to the athletes who did not strengthen their hamstrings. This observation has significant implications in knee injury cases because it identifies the importance of proper and directed strength training principles that may help to reduce injury. Therefore, it has been established that strengthening not only increases the size and tensile strength of a muscle, it also increases the speed at which the muscles react.\textsuperscript{7}

Ligaments or tendons function in a complex that involves either a bone-ligament-bone or bone-tendon-muscle unit respectfully.\textsuperscript{39} Most ligaments do not function as single units but act in concert (anterior cruciate ligament, medial collateral ligament) to resist discrete ROM activities at a particular joint position; one portion of a ligament may be taut while another portion may be slack.\textsuperscript{39}

A tendon functions as a transmitter of force produced by contractile and non-contractile elements within the muscle-tendon unit. Force is transmitted through tendon tissue to act on a bony segment and produce movement, or torque, on the segment about a joint axis. Tendons are considerably less flexible than muscle. This is because of their high composition of collagen. Collagen comprises 95\% of the tendon's tissue and will not change appreciably in length in response to loading. Under loading, collagen tissue will fail if stretched beyond 10\% of its normal length.\textsuperscript{13} Most physiologic stress on tendons from muscle contraction is well below this critical level for damage. However, even a strong tendon can fatigue with continued repetitive
submaximal loading. A tendon usually undergoes rapid failure with this continued loading past its ultimate stretch point.\textsuperscript{13}

According to Tipton and associates,\textsuperscript{45} when separation of a ligament or tendon occurs during injury, it is primarily at the site of insertion, the musculo-tendinous junction, and not in the tissue mid-substance. Furthermore, Kibler\textsuperscript{2} and Herring\textsuperscript{46} stated the musculo-tendinous junction is the most commonly injured site due to the relatively poor blood supply, particularly at the bone-tendon interface, which may contribute to injury production and delay healing.

While it would be convenient to assume that all ligaments and tendons respond equally to strength training, this is an oversimplification and should be avoided. For example, immobilization has more of an effect on the tibial insertion site than the femoral insertion site of the medial collateral ligament.\textsuperscript{39} Of the junctions tested, the medial collateral ligament junction was the weakest. This fact may partially explain its high injury incidence in athletic activity.\textsuperscript{2}

Ignoring the minor anatomical differences between ligaments and tendons, it is important to remember that each ligament and tendon is actually part of an anatomical and functional complex that includes not only the ligamentous structures and the bones which they attach, but the osteoligamentous insertions that are the transitions between ligament ends and bones. Interactions between the regions are critical in determining how the
complex reacts to various mechanical stimuli and, clinically, how they respond when injured.46

Research results have indicated that tendons and ligaments respond to physical activity in a fashion similar to muscles by: (a) increased metabolism, (b) increased thickness, and (c) increased weight and strength.13,45 Kibler and associates2 have documented that both muscle and connective tissue can undergo adaptations to physical training resulting in greater tissue mass and increased maximal tensile strength. Resistance training could aid in the prevention of injury by also increasing the strength of the connective tissue and bone.4 Furthermore, it has been well established that resistive training not only strengthens muscles, but also other structures around the joint which may aid in the prevention of injury.2

Tipton et al45 commented on the importance of specificity of exercise and its relationship to ligament-tendon strength. Changes in junction strength are dependent on the type of exercise performed and not solely on the time devoted to exercising. It has been further documented that eccentric strength training will significantly increase the strength of ligaments and tendons as opposed to concentric or isometric training.5,12

Historically, ligaments have been described as passive stabilizers of joints, while muscles were thought of as the dynamic stabilizers.5 The ligaments associated with a given limb joint are widely accepted as the structure responsible for its stability (i.e., preventing distraction of the bones
away from each other during loading). However, there is growing evidence that ligaments are partly responsible for influencing muscle activation patterns through reflex loops originating as sensory endings within the ligament and synapsing with motoneurons within the spinal cord.

Although there are many more anatomical and physiological determinates that quantify the effects of strengthening on the muscular and connective system, they are beyond the scope of this text. Important points to remember are: (a) muscle responds to the force applied to it by increasing its strength, (b) ligaments and tendons also increased in strength when external loads are forced upon them, and (c) there is a connection between muscular agonists and antagonists through a reflex arc system.

For strength training to be fully beneficial, the system must revolve around a balanced system of muscular ratios. That is, each agonist and antagonist muscle relationship also has its own inherent ratio that helps maintain the muscular system's normal biomechanics. Implementing a balanced strength training program into a training situation is a very simple and effective way to decrease the occurrence of muscular imbalance injuries. A comprehensive, but in no way all-inclusive, list of normal muscular balances within the human muscular system can be found in Table 2 in the appendix.

Furthermore, muscle activity, particularly synergistic, such as simultaneous quadriceps and hamstring activity, will help to control the motions of the joint and can help to prevent the tendencies of the joint to subluxate.
However, for this to be effective, a proper muscular balance between the agonist and antagonist must be observed. The proper muscular balance (ratio) helps to keep the ligaments from being stretched.\textsuperscript{7,42}

Wade and Moore\textsuperscript{47} took the idea of muscular balance to prevent injury a step further. These authors also included an athlete's weight and type of athletic event to determine the optimal strength ratio between the quadriceps and hamstrings. This type of training principle is directed towards the reduction of incidence of anterior cruciate ligament injuries. The authors contended that ACL injuries occur in a similar fashion in all types of athletic participation. The foundation of this strengthening technique is based on isokinetic testing at 60, 180, and 300 deg/sec. Sixty deg/sec is the equivalent of moving a limb at a maximum of 60 degrees every second, regardless of the force produced by the muscle. This is a slow and laborious movement similar to a powerlifting technique. A speed of 180 deg/sec is equivalent to the speed at which many sporting activities occur, and 300 deg/sec is equivalent to sprinting. Through this type of isokinetic testing, the authors have postulated that the hamstring/quadricep ratio increases with increased isokinetic speed. It is recognized that high schools generally do not have access to this type of equipment and therefore cannot be utilized. However, the authors established a mathematical equation that can be used without the use of isokinetic testing equipment. At 30 deg/sec, the hamstring/quadricep ratio was determined to be 0.67-0.77. That is, the hamstrings should be 67-77\% as strong as the
quadriceps at this particular speed. At 180 deg/sec, the ratio is increased to 0.80-0.91, and at 300 deg/sec, the optimal ratio is 0.95-1.11.

These above ratios can be very instrumental in determining optimal strength required by the hamstrings and quadriceps at a particular speed or stress. However, these ratios do not mean anything if there is no strength baseline for reference. Therefore, Wade and Moore\textsuperscript{47} determined the optimal strength of a quadriceps in relation to body weight and then implemented that into the athletic sport or position within the sport. They have determined the optimal quadriceps strength at 60 deg/sec to be 1.33 x body weight. That is, if an athlete weighs 250 pounds, his optimal quadriceps strength at this particular speed is 333 ft/lbs (1.33 x 250 = 333). At 180 deg/sec, the optimal ratio is .85; and at 300 deg/sec, the optimal ratio is .65.

Determining the optimal strength and balance of the quadriceps and hamstrings to help prevent the incidence of injury is specific for every athlete. For example, a 200-pound athlete's quadriceps strength goal at 60 deg/sec is 200 x 1.30 equal to 260 ft/lbs. Their hamstring strength goal at this same speed is 260 x .70 equal to 182 ft/lbs. However, a 150-pound athlete at the same speed has a quadriceps/hamstring goal of 195/136.5.

The muscular ratios listed above are exclusive to concentric strengthening. Values for eccentric training in the same manner have not been documented at this time. Furthermore, Tomberlin et al\textsuperscript{39} have stated that eccentric strength training techniques are commonly overlooked in strength
training programs, especially in the high school setting. Eccentric training can produce higher tensions in muscle than concentric contractions and, therefore, may provide a more effective stimulus for improved muscular performance. Eccentric training may also help in the treatment and prevention of muscle strains, during which injury is thought to occur in the eccentric phase of contraction.

A form of conditioning and strengthening that incorporates both concentric and eccentric muscular contractions is called plyometrics. Athletes who participate in sports that require explosive activities, such as sprinting and jumping, are recommended to include plyometric drills in their training programs. During a plyometric drill, also known as stretch-shortening cycle drill, a movement toward an intended direction is achieved by starting with a movement to the opposite direction. Crouching down before jumping is an example of a stretch-shortening technique. One of the most popular plyometric drills is drop jumping. Executing a drop jump involves jumping down from a height (usually 20cm) and, upon landing, performing a maximal jump. Athletes participating in training programs in which drop jumps were instituted have been reported to increase their vertical jumping achievement. Furthermore, research performed by Bobbert et al concluded that bounce drop jumps were best suited to provide the training stimulus required for a long-term improvement of knee extensors and plantarflexors to deliver force and power for increased jump height.
Kibler et al. concluded that maximally stimulated muscle, which can be produced through plyometric training, absorbs significantly more energy prior to failure than submaximally or non-stimulated muscle. It has also been demonstrated that a stronger muscle may absorb more energy than a weak muscle before reaching the point of muscular strain.

During a well balanced and directed training program, several factors are present that influence the development and strength of normal skeletal muscle. The first factor is the cross-sectional size of the muscle. The larger the diameter of the muscle, the greater the strength of the muscle. The length-tension relationship of a muscle at the time of contraction also influences strength. A muscle produces the greatest tension when it is slightly lengthened at the time of contraction. If a muscle is able to recruit a large number of motor units, the contraction will be stronger. The last factor that influences strength is the speed of contraction. The greatest amounts of torque are produced at lower speeds, due to the greater opportunity for motor recruitment.

In regard to an athlete beginning a strengthening program, he or she should begin with very light loads, preferably less than 50% of maximal negotiable load (1 max lift) at a minimal repetition level (10-12 reps). That is, if an athlete can maximally bench press 180 lbs one time, the preferable starting point for bench press should be between 80 and 90 lbs and they should lift that weight between 10 and 12 times.
Reasonably safe progress can be obtained with a gradual increase in repetition (or load duration) with the same load. For example, knee extension exercises with a 25-pound load at 12 times could be improved safely with the same load at a 10% increase in repetition (to 14 times). However, if athletes progress with weight training too quickly, they are at a higher risk of developing an overuse injury. That is due to the fact that the muscular system simply cannot maintain the force placed on it and injuries occur.

There have been many clinical trials performed in an attempt to justify or refute one form of strengthening over others regarding whether they primarily achieve: (a) hypertrophy, (b) greater strength, (c) metabolic adaptations, or (d) better muscle definition. However, as mentioned earlier, no definite consensus has emerged. All methods have shown improvement in all of the above areas, but there was no clear cut benefit documented for one method. It should also be remembered that regardless of the muscle strengthening techniques used, there was nearly always the occurrence of delayed soreness after activity, which according to Solomonow et al., due to mechanical damage to the muscle and its associated connective tissue. Therefore, conditions relative to minimizing trauma due to training should be employed in every training routine. In addition, one of the most important aspects for an individual who is starting weight training is the availability of the apparatus used, whether in the home or the gym, and the intrinsic desire to continue strengthening over time.
Specificity of strength training is an aspect of conditioning that needs to be reviewed. A proper stretching program designed to increase flexibility should be utilized in conjunction with balanced strength training for an athlete to function at peak performance. According to Maksud, flexibility is often the most neglected aspect of athletic training and a factor that influences sport performance. In general, stretching exercises to increase flexibility are performed during a warm-up and/or cool-down period. Also, during this time period, active muscular contractions are performed at a sub-maximal level. A warm-up period should increase the range of motion of the joints and muscle-tendon units, as well as increase the muscle temperature and the efficiency of the muscle contractions. It has been documented by several authors that the protective effect of warm-up is to increase range of motion or to decrease stiffness prior to warming up.

Safran et al demonstrated, in an in vivo rabbit model, that an exercised muscle required significantly more force to produce failure than the contralateral muscles that were not exercised. The authors concluded that a warm-up period
prior to participation may prevent injury to the musculotendinous unit by increasing its elasticity and force absorption capability.

The benefits of a warm-up period prior to and after activity have been debated. Clinical, non-quantifiable evidence indicated a reduced incidence of injury after a warm-up was performed. However, within recent years, experimental data regarding biomechanical explanations for injury reduction with warm-up have been documented. Although a large proportion of the recent scientific literature supports the physiological basis for the enhancement of performance and prevention of injury that results from warming-up, studies have produced confusing results due to improper control groups, lack of consistent methods, poorly designed protocols, and intra-individual variability.

However, it appears that with directed and consistent flexibility programs, the incidence and severity of muscular strains and sprains have decreased. Furthermore, in support of implementing such practices into a coaching regimen, it has been shown that strength training alone has a negative effect on joint mobility and flexibility. This can be counteracted by directed flexibility training. Flexibility is defined as the amount of movement of a joint through its normal plane of motion. Therefore, in regard to implementing a structured warm-up/cool-down program into an athletic conditioning routine, the training should be performed with the intent of improving performance through increasing flexibility and reducing the incidence of injuries. In addition, and very
importantly, warm-up and stretching routines are extremely athlete-and sport-specific.

In general, warm-up techniques are primarily used to increase body temperature and are classified in three major categories: a) passive warm-up increases temperature by external means; b) general warm-up increases temperature by non-specific body movements; and c) specific warm-up increases temperature by using the body parts that will be called upon in the subsequent, more strenuous activity. The best of these warm-up techniques appears to be specific warm-up because this method provides a rehearsal for the activity or event.56

According to Shellock and Prentice,56 the majority of benefits of warm-up are related to temperature-dependent physiological processes. An elevation in body temperature produces an increase in the dissociation of oxygen from hemoglobin and myoglobin. As well, warm-up lowers the activation rates of metabolic chemical reactions, increases muscular blood flow, decreases muscle viscosity, increases the sensitivity of nerve receptors, and increases the speed of neural impulses.

Different sports, and even different positions within a sport, may result in unique relationships between strength, flexibility, and injury risk because of the type of movements required. For example, extremes in flexibility may be desirable and even necessary for a gymnast, but the same degree of flexibility may be detrimental for a soccer or football player. Sports like football, field
hockey, and soccer all involve relatively continuous open field play, lateral movement, and body contact. Therefore, it is feasible to assume the athlete will require similar patterns of mobility in terms of strength, flexibility, and injury.

The limitations of joint flexibility have both an anatomical and physiological basis. Among the major anatomical factors are: (1) bone, (2) muscle, (3) tendon, and (4) components of the joint capsule including ligaments. Differences in human genetics and structural build influence the relationship of these structures and thus flexibility. Within the inherent structural limitations, flexibility is generally a function of soft-tissue components. That is, flexibility is elasticity.

Hypermobility is a condition that is the opposite of inflexibility. Hypermobile joints are moved in their normal plane of motion but beyond some predefined extreme point. Hypermobility is commonly seen in gymnasts and ballet dancers, as well as in athletes who participate in karate and yoga.

However, according to Sahrmann, flexible joints may become the site of undesirable motion. Often, movements that should be limited to one joint are not because of decreased flexibility. As a result, adjacent joints may compensate and an increase in flexibility results. An example of this is commonly seen in the flexibility relationship between the hamstring musculature and the low back area. If the hamstrings are inflexible or tight, the low back musculature must be stretched for normal range of motion to occur. Therefore, fault in one segment, the hamstrings, has an effect on another segment, the
low back. According to Knapik et al, subjects with either too much or too little flexibility in the low back-hamstring region respectively may be at a higher risk of injury.

In athletics, regardless of sport, one of the most common injuries seen is a hamstring strain/sprain. This injury often occurs during running, jumping, or kicking. Several authors have investigated the relationship between hamstring flexibility and hamstring injury. It has been postulated that decreased hamstring flexibility is a possible sequelae to hamstring muscle injury. Furthermore, the ability of connective and muscular tissue to absorb force is related to its resting length. The greater the resting length (flexibility), the greater the ability to absorb forces and avoid strain. Therefore, the importance of hamstring flexibility cannot be over-emphasized.

In general, the aims of flexibility training in injury prevention are to:

a) maintain and/or improve joint mobility, b) reduce the risk of joint overloading at extreme joint angles, c) increase muscle and tendon strength, d) enhance coordination between the various parts of the musculoskeletal system, and e) adapt the musculoskeletal system to the specific demands of a particular sport.

Furthermore, stretching techniques are based on a neurophysiological phenomenon known as the stretch reflex. Every muscle in the body contains various types of receptors which, if stimulated, inform the central nervous system of what is happening with the muscle. Two of these receptors are
important in the stretch reflex: the muscle spindle and the Golgi tendon organ (GTO). Both types of receptors are sensitive to changes in length of the muscle. The GTO is also affected by changes in muscle tension.\textsuperscript{15}

When a muscle is stretched, the muscle spindles are also stretched, sending a volley of sensory impulses to the spinal cord to indicate that the muscle is being stretched. Impulses return to the muscle from the spinal cord, which cause the muscle to reflexively contract, thus resisting the stretch.\textsuperscript{56} If the muscle stretch continues for at least six seconds, the GTO responds to the change in length by increasing in tension and firing off sensory impulses of its own to the spinal cord. The impulses from the GTO, unlike the signals from the muscle spindle, cause a reflex relaxation of the antagonist muscle. This reflex relaxation serves as a protective mechanism to allow the muscle to stretch through relaxation.\textsuperscript{54}

When implementing a stretching program into an athletic conditioning program, the stretching should be done before vigorous athletic activity, but preferably after a 5-10-minute warm-up. According to Solomonow et al,\textsuperscript{50} passive stretching has been shown to substantially reduce soreness if done immediately after exercise.

Maximal flexibility is achieved if two to three prolonged stretches are performed when the muscle tissues are warm from exercise. When a muscle group is tight, it should be stretched two to three times daily. After optimal
Flexibility has been achieved, once-daily maintenance stretching, before and after exercise, is sufficient.\textsuperscript{51}

Stretching is one of the most important aspects of flexibility training. It has been documented that flexibility exercises should be started after the growth spurt (i.e., at age of 15-17 years), when there is rapid increase in muscle volume and power.\textsuperscript{20} This has very important implications for all high school aged people, but especially in regard to athletes.

There are two basic forms of flexibility, static and dynamic. Static flexibility is defined as the range of motion about a particular joint.\textsuperscript{39} Static stretching is the method most commonly used by athletes when stretching is done without assistance. A full, non-restricted range of movement can gradually be attained through static stretching.\textsuperscript{56} The targeted muscle group is stretched until the familiar pulling sensation, short of pain, is achieved. That position is held for about 30 seconds. This is repeated two to three times for each muscle group.\textsuperscript{51} The static stretch needs to be long enough in duration for the GTO to begin responding to the increase in tension. The impulses from the GTO have the ability to override the impulses coming from the muscle spindles, allowing the muscle to reflexly relax following the initial reflex resistance to the change in length. This lengthens the muscle and allows it to remain in a stretched position for an extended period, thus making the muscle less likely to be injured.\textsuperscript{56} With static stretching, there is less danger of
exceeding the extensibility limits of the involved joints because the stretch is more controlled.

Dynamic (ballistic) flexibility refers to the resistance of a joint to motion or movement. Ballistic stretching involves repetitive movements or bouncing against the limits of the joint’s range of motion. This method may enhance flexibility, but there is a risk of exceeding the joint's normal range of motion and tissue damage may result. With this type of stretching, the muscle spindles are repetitively stretched and there is continuous resistance from the muscle to further stretch. In addition, the ballistic stretch is not normally continued long enough to allow the GTO to activate and produce any relaxing effect. This technique is rarely used and care should be taken when implemented into a stretching regimen.

Proprioceptive Neuromuscular Facilitation (PNF) techniques were first used by physical therapists to treat patients with various types of neuromuscular paralysis. Only recently have PNF stretching exercises been used for increasing flexibility in athletes. There are a number of PNF techniques currently being used for stretching, including slow-reversal hold, contract-relax, and hold-relax techniques. The effectiveness of PNF stretching techniques may be attributed to the same neurophysiological principles as static stretching. All involve some combination of alternating contraction and relaxation of both agonist and antagonist muscles. PNF techniques usually involve a 10-second pushing phase followed by a 10-second relaxation phase.
Using the hamstring stretching technique as an example, the slow-reversal hold technique could be implemented with the athlete lying on his/her back, with the knee extended and the ankle in a neutral position. A partner would passively move the knee into hip flexion, to the point where slight discomfort is felt in the muscle. At this point, the athlete would push his leg down against the partner's resistance by contracting the hamstring muscles. After pushing for ten seconds, the hamstring muscles are relaxed and the agonist hip flexors are contracted while the partner applies passive pressure to further stretch the antagonist hamstrings.

This stretching technique should move the leg into increased hip flexion, thus stretching the hamstring musculature. The relaxation phase lasts for ten seconds. During this time, the individual again pushes against the partner's resistance, beginning at this new joint angle. This push-relax sequence is typically repeated at least three times.\(^5^6\)

The contract-relax and hold-relax techniques are variations on the slow-reversal hold method. In the contract-relax method, the hamstrings are isotonically contracted so that the leg moves toward the floor during the push phase. The hold-relax method involves an isometric hamstring contraction against immovable resistance during the push phase. Both techniques involve a relaxation phase of the hamstrings, while the hamstrings are passively stretched. These two basic techniques can be used to stretch any muscle in the body.\(^1^5,^5^6\)
In summary, before implementing an aggressive stretching program into any athletic training regimen, a knowledgeable background into the subject and care should be observed. It should be stated once again that studies produced in attempts to show a positive correlation between stretching exercises and the decrease of athletic injuries are very limited and often times have misleading results. Furthermore, it may be more important at the high school level to teach proper and correct stretching techniques as part of a warm-up routine to decrease the occurrence of injury, rather than focusing directly on stretching to increase range of motion.
CHAPTER 5

FATIGUE

Muscular fatigue is characterized by reduction in the ability of the muscle to generate its normal strength and endurance levels after vigorous exercise. During strenuous exercise, the activation of all the motor unit population (both fast and slow twitch fibers) of a muscle occurs. The white fibers are the first to fatigue when large force levels are generated by the muscle and ischemic conditions occur. Ischemia is further compounded by the poor vascularization of the white muscle fibers. The supply of oxygen, sugar, and proteins necessary for contraction is disrupted, as well as the ability to remove waste products. This situation produces anaerobic conditions that result in rapid fatigue of the white muscle fibers. As exertion continues, the effects of fatigue can influence the red muscle fibers for the same reasons. Generally, the vascularization of the white muscle fibers and their partial conversion to red fibers gradually improves during increased physical activity or training. The complete conversion of white fibers has not been reported in the literature. The fiber conversion is reversed to a degree for athletes during prolonged periods of inactivity, which explains the reduction of limb girth, strength, and endurance when activity is ceased.
Delayed muscle soreness appears 12-48 hours after exercise and is characterized by a diffuse area of pain, tenderness, and stiffness in the muscle. There is a significant amount of controversy in the literature regarding specific reasons for the presence of delayed muscle soreness.\textsuperscript{50} Regardless of the controversies, many agree that mechanical damage to the muscle and its connective tissue occurs.\textsuperscript{2,12,50,51} To minimize the trauma that occurs in the muscle due to training, the progression of exercise must be gradual. The muscular system needs to adapt gradually to increased loads.

There are various types of fatigue, including neuromuscular fatigue and fatigue due to calcium depletion in the muscles sarcomere. However, the description of these is beyond the scope of this paper. It should be remembered that, in general, fatigue occurs in relationship to blood flow, the general circulatory conditions, and the relationship of oxygen and glycogen supply to waste removal. Measures need to be initiated to reduce the severity and occurrence of fatigue due to strenuous training. Some of the basic measures include proper rest, replenishment of nourishment, and hydration.\textsuperscript{50}

The benefits of implementing structured strength, endurance, and flexibility training into a sporting situation are performance improvement and injury reduction.\textsuperscript{38,59} As an example, year-round conditioning specifically designed for basketball has reached a high level of sophistication over the last few decades.\textsuperscript{38} Through research, major components of conditioning for basketball have been shown to improve anaerobic power, aerobic power, as
well as muscular strength, power, endurance, and flexibility. The concept of year-round conditioning uses the principles of periodization in work and rest to achieve peak performance and avoid injuries.38

All training programs must have a specific goal in mind.12 A defined goal in athletic strengthening and training may be defined as "specificity." Specificity of training is a crucial element in the proper training of athletes. A coach or trainer must know which structures to train and strengthen and why before he/she can expect reasonable improvements or a decrease in injuries. As well, a coach or trainer is usually the athletes only link between health and fitness. A coaching philosophy based on the idea that increased strength is directly related to increased athletic performance may prove more harmful than good in the long run of the athlete's career.

The information that has been presented on strength and flexibility training, as well as fatigue, is in no way all-inclusive. It should also be mentioned that training for each sport requires special adaptations. Furthermore, much more research is needed to adequately and justifiably determine the benefits of athletic strengthening and conditioning in an attempt to decrease the occurrence and severity of injury.
CHAPTER 6

OVERUSE INJURIES

Since the 1950s, there has been an abundance of material produced that adequately identifies the risk factors associated with specific types of athletic events and participation.\(^3\) There is also an abundance of literature that identifies non-specific athletic injuries or injuries that are common in all sports due to multi-factorial causes. Many of these injuries can be classified as overuse injuries. Overuse injuries account for 10% of all sports injuries.\(^{24}\) Other studies have shown this percentage to be approximately 30 to 50%.\(^{45}\) Further, 50% of all overuse injuries can be attributed to training errors.\(^{20}\) The prevalence of overuse injuries is directly related to the concept of overtraining. Muscle overload injury has been documented as the most common type of athletic injury, comprising up to 67% of injuries, depending on the sport.\(^2\) Overuse injuries due to overtraining have significantly risen over the past decade. Because competitive athletic activities, by nature, require high volumes of training at a high intensity, the risk of overtraining to the musculoskeletal system and subsequent adaptation is always present in this population.\(^2\)
Injuries due to overtraining can occur nearly anywhere within the limits of the musculoskeletal system. These injuries have been defined by Kibler et al. as a series of physiological, biomechanical, and anatomical stresses that eventually cause either a relative or an absolute force overload. Overuse injuries occur when a relative force load evolves from repeated applications of forces of normal magnitude that eventually overcome the ability of a compromised muscle to withstand the force. An absolute force overload would exist when the applied force or summation of forces is of greater magnitude than the normal musculoskeletal system can withstand.

Overuse injuries occur as a result of repetitive microtraumas rather than one specific macrotrauma; i.e., a broken leg or ruptured anterior cruciate ligament. Overuse injuries also result due to a number of intrinsic and extrinsic factors. Extrinsic factors are conditions that are controlled by training and are easily changed or controlled. Intrinsic factors are inherent within the athlete's own individual anatomic abnormalities and are not so easily controlled.

Within this paper, only the extrinsic factors such as strengthening, flexibility, and fatigue have been covered. Furthermore, it is far beyond the scope of this paper to attempt to identify all types of overuse injuries. Instead, a background to overuse injuries and how they relate to specific musculoskeletal systems will be reviewed. These include: (a) muscles, (b) tendons and ligaments, (c) bones, and (d) nerves. Common examples of
injuries labelled as overuse injuries are, but are not limited to: a) stress fractures, b) shin splints, and c) golfer/tennis elbow.

On the cellular level, overtraining has been associated with tissue catabolism, which is a destructive form of metabolism that breaks down substances into simpler forms. This may be the result of overtraining. Relative to musculoskeletal injuries, the catabolic state induced by overtraining may be directly related to maladaptations that would increase the chance of overload injuries. Although overuse injuries can affect a variety of tissues and anatomic sites, they share a common etiology: repetitive trauma that overwhelms the tissue's ability to repair itself. Adaptions in flexibility or strength result as the body attempts to compensate for the overuse injury. Often times, these adaptations can only be discovered in retrospect, after an overt injury has occurred or if a deleterious adaptation has been identified.

Many overuse injuries can be avoided or lessened in severity via several methods: (a) a thorough screening process of strength and flexibility must be performed before and regularly during the season, (b) a good sport-specific conditioning program is necessary to give the athlete a strong musculoskeletal base on which to build athletic skills and decrease the risk of overtraining adaptions, (c) prehabilitation exercises in the form of balanced strength training can be performed for those musculoskeletal areas that are under high stress in a particular sport, and (d) maintenance of a conditioning program that extends beyond the regular season to decrease the occurrence of injuries due to the
high stresses during pre-season conditioning. Overuse injuries, regardless of
the site, share a common etiology and are often times determined by several
extrinsic factors. These include: (a) poor flexibility, (b) improper strengthening,
(c) muscle imbalances, (d) improper warm-up, and (e) overall poor training
techniques. Therefore, at the very basic level, in order to avoid injuries in muscles
and other anatomical tissues, special attention is required from athletes and
their coaches to the importance of cautious progression. This is especially true
in adolescent and high school athletes. Zito reports that young athletes are
being exposed to high-intensity training at earlier ages. As a consequence,
overuse injuries, which were traditionally described in more mature athletes, are
now being recognized in adolescents. Furthermore, the immature
musculoskeletal system is less able to cope with the repetitive biomechanical
stresses. In the growing skeleton, three areas are particularly susceptible to
overuse injuries: (a) the epiphyseal plates, (b) the joint surfaces, and (c) the
apophysis.

Generally speaking, the tissue most commonly affected by an overuse
injury is the tendon. The most common site of injury within the tendon is the
musculo-tendinous junction. Tendinitis, or inflammation of the tendon, can be
sudden and seemingly unrelated to overtraining. Through research it has been
confirmed that achilles tendinitis is the most common injury in sports. Other
common examples include: (a) supraspinatus and biceps tendinitis in the
throwing athlete, (b) patellar tendinitis in the volleyball and basketball player, (c) and iliotibial band tendinitis in the runner.

Lateral/medial epicondylitis (tennis/golfer’s elbow, respectively) are also examples of overuse tendon/bone injuries seen in the athletic population. These injuries are primarily seen in throwing and racquet sports (hence the common names). It has been estimated in a recent study that 45% of the tennis players researched have suffered from this type of injury. Conditions that exist to predispose an athlete to this type of injury have been identified as: (a) improper stroke mechanics, (b) imbalance/weakness of the wrist musculature, (c) inflexibility of the wrist musculature and, (d) improper warm-up.

Achilles tendinitis primarily affects the tendons of the plantarflexor musculature of the foot. Lateral/medial epicondylitis primarily affects the bony origins of the wrist extensor/flexor musculature. However, the baseline causes of these injuries are quite similar. These common factors, once again, include: (a) poor flexibility, (b) weakness, (c) muscular imbalances, and (d) poor training techniques.

Therefore, to decrease the occurrence of tendinitis, techniques used to increase flexibility, balance strength ratios, and reduce the severity of fatigue need to be incorporated into an athlete’s conditioning program. As mentioned earlier, tendons respond similarly to muscle with regard to increased mass and density with resistance training. It is further indicated that resistance training also may increase the junction strength within the musculo-tendinous unit.
Increased strength of the tendons and muscles would allow the system to absorb greater forces and lessening the force transmitted to the bone. Furthermore, it has been established that tendons respond best to eccentric training.\textsuperscript{33}

Ligaments are physiologically very similar to tendons. Ligaments also respond to resistance training similarly to tendons by increasing metabolism, thickness, weight, and strength.\textsuperscript{4,20} Probably the most easily recognized form of ligamentous injury is the chronic ankle sprain. Lack of strength and flexibility at the ankle joint is the most common cause of initial injury,\textsuperscript{2} and muscular weakness and inflexibility is the primary cause of chronic overuse ankle injuries. These injuries occur/re-occur very suddenly and are due to the fact that the ligamentous tissue at the ankle joint does not heal well after an initial injury, which makes the predisposition to recurrence very high. This inability to heal is due, in part, to the physiology and poor blood supply to the ligament. Isolated strength training before injury occurs to the musculature around the ankle joint, is mandatory for the reduction of ankle injuries. If strength training is initiated at the ankle prior to injury, the chance of an injury occurring is substantially decreased.

Bursitis is also a common result of overtraining. A bursa is a sac formed by two layers of synovial tissue located at sites of friction between tendon and bone or skin and bone. In their normal state, they contain a thin layer of synovial-like fluid. With overuse, friction on the bursa from an overlying tendon
or ligament may cause the bursa to become inflamed, with resulting effusion and thickening of the bursal wall. Thus bursitis is developed.\textsuperscript{46}

In addition, bone is also a common site of overuse injury. Overuse injuries in bone are classified as stress or fatigue fractures. In the 1980s, 10% of the injuries seen in sports medicine practices were stress fractures.\textsuperscript{2} The ability of the bone to withstand repetitive loading depends on: (a) the amount of the load, (b) the number of repetitions, and (c) the frequency of loading. Stress fractures occur when the fatigue process outpaces the ability of bone to repair itself. In addition, stress fractures can be related to muscle strength imbalance, inflexibility, muscle weakness, or abnormal mechanical loads on the bone.

There are several theories regarding the biomechanical basis of stress fractures. One view is that during continuous strenuous activity muscles fatigue. As the muscles tire, they become less able to absorb energy and reduce the stress that is transmitted to bone.\textsuperscript{7,46} This altered stress distribution allows abnormally high forces to be transmitted to bone, and a fatigue fracture may occur. A different belief exists that disagrees with the previous statement. Simply stated, it is believed that the force of the muscles themselves acting upon their insertions into the bone create the repetitive stress that ultimately leads to a bone fracture.\textsuperscript{46}

Regardless of how stress fractures occur, they have been reported in almost every bone in the lower extremity, the pars articularis in the spine, and
even in the non-weight bearing bones in the upper extremities. Stress fractures are much more common in the athlete with a history of endurance training or repetitive movements. A sudden increase in the amount of competition or intensity predisposes athletes to fatigue or stress fractures.

Nerve tissue is also subject to overuse injury. Repetitive motion and loading, muscular hypertrophy, direct trauma, decreased flexibility, and altered biomechanics have all been implicated in nerve entrapments of the athlete. Although nerve injuries are commonly caused by the factors listed above, they produce a much more difficult problem to overcome. If a nerve becomes entrapped, motor activation and sensation below the level will be affected. Parasthesia may develop, as well as motor weakness. If the nerve entrapment is serious enough, surgical intervention is usually the only way to alleviate the condition.

Some injuries are quite common; i.e., tennis elbow and shin splints, whereas others are not quite so common or recognizable; i.e., osteochondritis dissecans and patellar tendinitis. Regardless of the name given to the injury, the prevention of the injury is usually the same. Overtraining places a demand on the musculoskeletal system, and therefore functional and biomechanical adaptations occur which may be detrimental to the athlete’s performance.
CHAPTER 7

MUSCLE IMBALANCES

According to Kibler et al.,\textsuperscript{2} adaptations of the muscular system in terms of strength training may actually be deleterious to both performance and injury prevention if muscle imbalances are present. Both muscle imbalances and muscle weakness have been demonstrated in athletes. Muscle imbalances between the agonist and antagonist muscles that cross a joint have been suggested as possible causes of sports related injuries.\textsuperscript{2,10,14,30,36,42,43,51,60,63,65} It has also been speculated that overtraining is a factor in the creation of these muscle imbalances.\textsuperscript{2,8,23,35,51,53,63,64,66}

An example of poor training technique is one that focuses specifically on a particular muscle group at a specific joint. Improper training primarily involves the agonist or prime mover and ignores the opposite muscle group, the antagonist, thus creating a muscular imbalance.

A muscular imbalance commonly seen in the athletic population is the relationship between the anterior and posterior muscles of the shoulder complex. The muscles of the anterior shoulder complex are generally strengthened substantially more than the posterior shoulder muscles. This imbalance, if left untreated, will lead to an overuse type injury of the posterior
shoulder muscles. That is, the posterior shoulder muscles are functionally too weak to compete with the anterior shoulder muscles. This imbalance will eventually cause a strain on the shoulder capsule, thus predisposing the athlete to an injury that easily could have been avoided through balanced strengthening techniques.²,8-10,14,16,23,35,41,46,57,63,67

Another example of muscular imbalance occurs in the internal/external rotators. Because of the nature of their sports, both swimmers and baseball pitchers have an increased strength of the internal rotator (IR) musculature as opposed to their external rotator (ER) musculature. As well, many of the strengthening exercises performed by these athletes are directed towards strengthening of the internal rotator muscles. That is, the athletes are strengthening the muscles that best perform the sport specific action (throwing) required of them. However, the muscles that help control that motion and slow the arm down after the ball has been released are generally ignored.⁵⁴,⁶⁸-⁷⁰

This increased IR strength and decreased ER strength causes a change in the length tension relationship of the shoulder muscles. Because of the compensation needed to overcome this imbalance, other muscles must work at a disadvantage while attempting to keep the system functioning at peak levels. Eventually, the muscles working in a compensatory fashion become fatigued and the athlete is at a predisposition to a shoulder injury.⁵⁴,⁷⁰

Continuing with muscular imbalances, another common injury that occurs is anterior tibial strain (shin splints). This type of injury is associated with pain
along the anterior, lateral tibia and is especially common among beginning runners or at the beginning of the training season. When a person runs, the anterior tibialis muscle dorsiflexes the foot against the action of the posterior muscle group, the gastrocnemius and soleus. The injury often occurs due to weakness of the anterior tibialis muscle as it opposes the posterior muscle group. According to Davies,\textsuperscript{11} the correction or prevention of this type of injury is to strengthen the anterior tibialis muscle in the correct ratio as compared to the gastrocnemius and soleus.

Continuing with improper training techniques, it was believed for many years the "no pain, no gain" theory was the only and best way to strengthen an athlete. Today, however, with the prevalence of the year-round and multi-sport athlete, the increased occurrence of athletic 'burnout' and injuries due to overtraining are becoming greater and greater factors. It is for these reasons many research articles are being published that explain the benefits of specific training techniques that decrease the occurrence of athletic burnout and overuse injuries.\textsuperscript{2,3,5,43,46,50,62,65}
CHAPTER 8

CONCLUSION

Athletic activity is a major part of many young people's lives. Millions of high school athletes compete in athletic events for nearly the entire year. With this high number of athletes participating, there are bound to be many injuries as well. In the high school system, it is the job of the athletic coaches and/or trainers to help keep the athletes at the top of their game emotionally, psychologically, and physically. Proper strength, flexibility, and conditioning training are major components of an athlete's regimen. Unfortunately, injuries occur in all levels of athletics for many avoidable reasons. However, research has shown that many of the injuries commonly seen in the athletic population can be avoided using balanced strength techniques, flexibility training, and conditioning. However, being able to recognize improper training techniques is a difficult job, and it takes close, structured observation by coaches to prevent improper techniques. Incorporating proper strength and flexibility techniques into a training regimen should not be a difficult adjustment to make. Many of the techniques discussed are simply expansions or adjustments to already present training procedures.

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Overuse injuries are becoming a greater and greater cause of missed playing time. Developing and following techniques designed to avoid such injuries is a basic component for good athletic training. It should be further expanded that simply employing these techniques will not drastically alter an athlete's performance nor will all injuries be eliminated. They are designed specifically for the prevention of injuries. Also, these techniques will benefit the athlete by increasing strength and flexibility.
APPENDIX
Table 1. Participants and Injuries Incurred in 19 Sports

<table>
<thead>
<tr>
<th>Sport</th>
<th>Sex</th>
<th># of Team Seasons</th>
<th># of Participants</th>
<th># of Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross-country</td>
<td>M</td>
<td>8</td>
<td>141</td>
<td>41</td>
</tr>
<tr>
<td>Cross-country</td>
<td>F</td>
<td>4</td>
<td>26</td>
<td>9</td>
</tr>
<tr>
<td>Football</td>
<td>M</td>
<td>8</td>
<td>624</td>
<td>506</td>
</tr>
<tr>
<td>Volleyball</td>
<td>F</td>
<td>7</td>
<td>174</td>
<td>17</td>
</tr>
<tr>
<td>Badminton</td>
<td>F</td>
<td>1</td>
<td>16</td>
<td>1</td>
</tr>
<tr>
<td>Basketball</td>
<td>M</td>
<td>8</td>
<td>275</td>
<td>84</td>
</tr>
<tr>
<td>Basketball</td>
<td>F</td>
<td>6</td>
<td>114</td>
<td>29</td>
</tr>
<tr>
<td>Gymnastics</td>
<td>M</td>
<td>1</td>
<td>18</td>
<td>5</td>
</tr>
<tr>
<td>Gymnastics</td>
<td>F</td>
<td>5</td>
<td>98</td>
<td>39</td>
</tr>
<tr>
<td>Swimming</td>
<td>M</td>
<td>1</td>
<td>77</td>
<td>1</td>
</tr>
<tr>
<td>Swimming</td>
<td>F</td>
<td>5</td>
<td>82</td>
<td>7</td>
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<tr>
<td>Wrestling</td>
<td>M</td>
<td>8</td>
<td>234</td>
<td>176</td>
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<tr>
<td>Baseball</td>
<td>M</td>
<td>8</td>
<td>249</td>
<td>46</td>
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<tr>
<td>Soccer</td>
<td>M</td>
<td>5</td>
<td>139</td>
<td>42</td>
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<td>Tennis</td>
<td>M</td>
<td>3</td>
<td>114</td>
<td>3</td>
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<tr>
<td>Track &amp; Field</td>
<td>M</td>
<td>8</td>
<td>308</td>
<td>101</td>
</tr>
<tr>
<td>Track &amp; Field</td>
<td>F</td>
<td>8</td>
<td>208</td>
<td>73</td>
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<tr>
<td>Softball</td>
<td>F</td>
<td>1</td>
<td>16</td>
<td>7</td>
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Table 2. Isokinetic Norms of Skeletal Muscle Ratios (degrees/sec)

<table>
<thead>
<tr>
<th></th>
<th>30 degrees/sec</th>
<th>45 degrees/sec</th>
<th>60 degrees/sec</th>
<th>90 degrees/sec</th>
<th>20 degrees/sec</th>
<th>180 degrees/sec</th>
<th>240 degrees/sec</th>
<th>300 degrees/sec</th>
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<tbody>
<tr>
<td><strong>Ankle Norms</strong></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Plantarflexion/Dorsiflexion</td>
<td>4:1</td>
<td>N/A</td>
<td>3.5:1</td>
<td>N/A</td>
<td>3:1</td>
<td>2:1</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>Inversion/Eversion</td>
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<td>N/A</td>
<td>1:86</td>
<td>N/A</td>
<td>1:83</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td><strong>Knee Norms</strong></td>
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<tr>
<td>Extension/Flexion</td>
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<td>N/A</td>
<td>1:60-69</td>
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<td>N/A</td>
<td>1:7.79</td>
<td>1:8.89</td>
<td>1:85-95</td>
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<td>1:2.95</td>
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<td>1:4.06</td>
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<td>N/A</td>
<td>1:56</td>
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<td>Dominant arm 15% increase adduction torque</td>
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<td>Dominant arm 10% increase adduction torque</td>
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<td>Flexion/Extension</td>
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<tr>
<td>Internal/External Rotation</td>
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<td><strong>Elbow Norms</strong></td>
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<td>Flexion/Extension</td>
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REFERENCES


