USTA SPORT SCIENCE COMMITTEE WHITE PAPER ON

TENNIS TECHNIQUE AND INJURY PREVENTION

Tennis Technique, Tennis Play, and Injury Prevention

USTA Sport Science Committee
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Purpose

The purpose of this white paper is to review current research on tennis play and to present coaching applications related to tennis technique, tennis play, and concepts of injury prevention. This paper specifically addresses (1) Tennis injuries: types and causes; (2) The role of conditioning and warming up; (3) The effect of racquets and surfaces; and (4) The evidence relating technique to injuries.

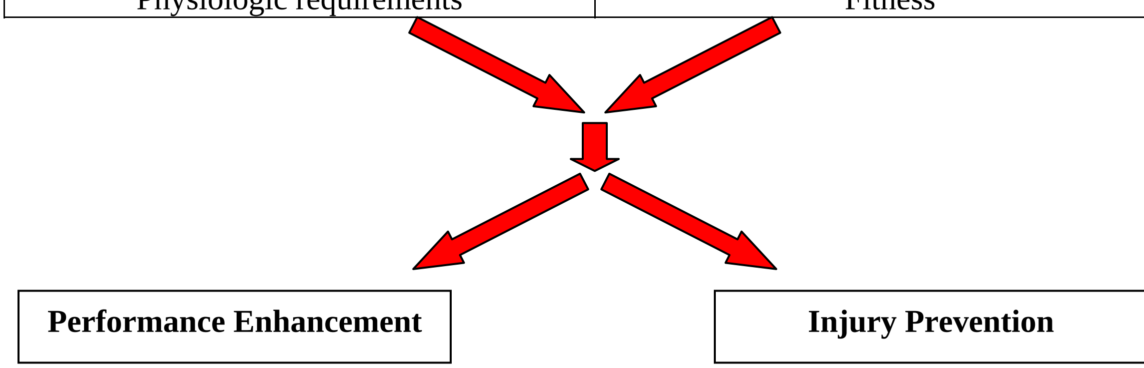
Overview of Injuries in Tennis

One of the major goals of teaching tennis is to maximize tennis performance while minimizing risk of injury. Much effort has been devoted to identifying factors related to tennis play and tennis technique that may influence the risk of injury in tennis play. These factors that have been identified may be grouped two categories:

1. Sport specific demands such as the court surfaces played on, the environmental conditions, and event the physiological requirements of the sport.
2. Individual based factors like technique, style of play and even fitness levels

These two groups of factors can interact to influence tennis performance and injury risk as shown in the accompanying diagram.

Sport Specific Demands	**Individual Factors**
Court surfaces	Ball striking technique
Equipment	Style of play
Environment	Strength
Physiologic requirements	Fitness



The major evidence relating tennis play to injury suggests that the individual factors create a specific capability to play tennis on an individual level. This capability interacts with the demands that are inherent in high-level tennis. Coaches and medical practitioners should closely evaluate and maximize the individual capabilities as well as understand the inherent demands of the sport in order to reduce injury risk.

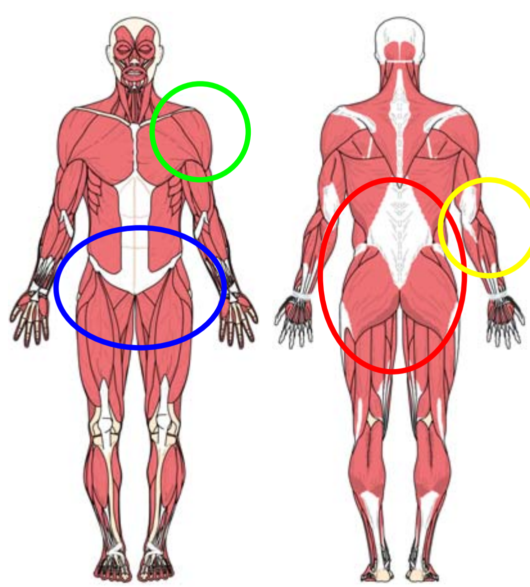
Tennis Injuries: Types and Causes

Tennis injuries are of 2 broad types:

- ***Traumatic injuries*** (sprains, muscle pulls, fractures, etc) make up about 1/3 of injuries seen in tennis, depending on the age and activity level of the player. Most traumatic injuries occur in the lower extremity. They are not easily prevented, nor are they particularly related to tennis technique.

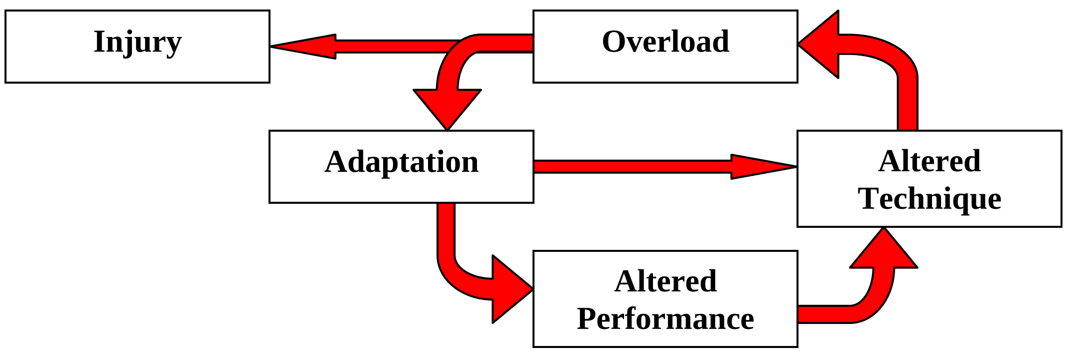
- ***Overuse injuries*** (strains, tendonitis, tendinosis low back pain, etc) comprise about 2/3 of injuries experienced by tennis players. Overuse injuries occur in all areas of the body, and may be related to technique or to alterations in the athlete's musculoskeletal system.

There are multiple causes for the overuse injuries in tennis, including the need to perform repetitive forceful motions and strokes, inadequate rest and recovery, incorrect tennis specific conditioning, acquired inflexibility, and strength weakness/imbalance. Each injury may have unique causes that must be evaluated to avoid repeated injury, suggest proper conditioning programs, and allow safe return to sport.



Long-term tennis play has been shown to result in adaptations in flexibility, strength, and strength balance in many areas of the body. The most commonly involved areas include **the hip**, **the low back,** **the shoulder,** and **the elbow**. As a result, the athlete may exhibit inflexibility in hip rotation, inability to touch the toes, inflexibility in shoulder rotation, and tightness in elbow extension or forearm rotation. They also may show weakness in trunk or shoulder muscles. These adaptations usually don't produce injury by themselves, but create a less than optimal capability to withstand the inherent physiological or mechanical demands the athlete must face in playing tennis. This creates the process of overload which then can lead to further adaptations, alterations in technique, and alterations in performance, with the potential to cause injury over time, as shown in the diagram of the "negative feedback vicious cycle" of injury.

Vicious Cycle of Adaptation and Injury



Other causative factors in injury risk include the need to hit repetitive forceful shots over many matches, inadequate rest and recovery between matches or practice, and conditioning programs that are not specific enough to prepare the body for the tennis specific demands. All of these feed in to the negative feedback cycle to increase the risk for injury.

Coaching Applications

- **Coaches should develop a systematic method of measuring and evaluating for the athlete's musculoskeletal base or physical fitness level in order to identify potentially injurious adaptations. The USTA has developed the *High Performance Profile* that can be used for this purpose. Since the athlete's musculoskeletal structure can change over time, either due to growth or as the result of continual play in adults, this exam should be used at least every year to know precisely the state of the athlete's capability to withstand the demands of tennis.**

- **Coaches should also review the athlete's schedule of matches and practice times, and allow sufficient time for rest and recovery within the schedule. A good guideline suggested by many experts is at least 1 full day of rest during each 7-day cycle.**

- **Coaches should be familiar with the athlete's off court conditioning program and should make sure that it conforms to the principles of periodization; this plan should ensure that the players perform sport specific exercises and peak for the important matches.**

(Continued)

- **Finally, if the athlete does experience an injury, the coach should become a part of the treatment program by checking for any tennis related causes, such as match play overload, poor conditioning, or poor stroke technique, and helping to correct the underlying problem.**

The Role of Strength Training, Conditioning, and Warming Up

Because many parts of the tennis player's body experience high loads on a repetitive basis, the musculoskeletal system must be prepared to withstand these loads. Much research has shown that an athlete cannot just play a sport to get in maximum shape for that sport, so a tennis player's training plan should include a structured conditioning program that includes more than just playing tennis. Conditioning for tennis requires the exercises to be specific for the demands of tennis, and to be performed in a periodized manner in order to balance the workout load between conditioning and practice/play.

Periodization

Periodized conditioning breaks the tennis season into four periods, each with specific training and conditioning goals. The four phases are:

1. The preparation phase. The preparation phase emphasizes maximal off-court work to improve general flexibility, strength, and endurance. Total body flexibility exercises, core and leg strength exercises, and running make up the bulk of the conditioning program. There is relatively little tennis play in this period.
2. The pre-competition phase (or transition phase) sees an increase in the amount of tennis played, and focuses more on tennis specific exercises, which would include shoulder and arm flexibility, shoulder and arm strength, and short run activities. The emphasis of this phase should transition from building muscle endurance to training for strength and power.
3. The competition phase is a high-intensity play period when tennis is played at a maximal level. Conditioning during this phase should emphasize maintenance exercises such as shoulder and trunk flexibility, scapula and rotator cuff strength, and anaerobic endurance sprints.
4. The rest and recovery phase is a period when the player can recover from the physical and mental stress endured during the competitive season. Rest and recovery must be built into all phases of the training plan to decrease the tennis loads, but it is especially important to allow some down time. The player should still work to maintain a fitness level but this can be done through cross-training Players should stay away from serious tennis training.

Because the tennis season may be prolonged and not have definite off times, these periods of conditioning must be carefully tailored to the player's competitive goals.

Warm-up

Warm up immediately before play is more beneficial for maximal muscle performance and reduced injury risk than static stretching, which should be performed between matches or after a match or practice.

Research shows that flexibility has two components, a static component that relates to how far a joint or muscle can be stretched, and a dynamic component that relates to how the tension within the muscle rises with a stretching action. Both components play a role in preparing for play and in protecting against injury.

The static component is easily measured by standard tests and can be modified by the traditional stretching exercises. It appears that the classic stretch and hold for 15- 30 seconds technique is a good method of increasing joint flexibility. This type of stretching, however, has been shown by research to be harmful to performance if done immediately before play. This type of stretching should be performed in the cool down after matches and between matches or practices. Static stretching is not recommended during the warm up because it has been shown to decrease muscle strength, maximum muscle activation, and quickness of muscle activation for more than 60 minutes after the stretching ends. Also, classic stretching by itself prior to vigorous activity has been shown to have no effect on muscle or tendon injury protection.

The dynamic component of flexibility may be more related to actual tennis play, and is best addressed by performing a proper warm up. Performing a proper warm-up is essential to both improved on-court performance and reduction in injury risk in tennis play. "Warm up" is exactly what it says- the internal temperature of the muscles and joints must be elevated to allow maximum pliability of the tissues. Muscle that is warmed through active contractions has been shown to be able to elongate more and absorb more energy before injury than when the muscle is cold.

The primary principles of an active warm-up are the gradual increase in intensity of muscle contractions, the progression from general to specific activity, and the use of the muscles and joints in positions and motions that will be used in tennis. Tennis players should begin the general activities with whole body movements such as walking, bicycling, or jogging at low to moderate intensities (40- 60% maximum) for 5 – 10 minutes. Specific activities would include trunk and arm rotations, leg lunges and bends, and racquet swings in all stroke patterns. These should be performed at medium speeds through full arcs of motion. See the USTA DVD entitled *Dynamics Tennis Warm-Ups* for more information on exercises to perform in this phase. This should be followed by some light hitting. High intensity stroking should only begin after 5 minutes of gradually increasing stroke intensity.

Coaching Applications

- **Tennis specific conditioning and warm up are key elements in minimizing the potentially dangerous adaptations that can occur with long-term high intensity tennis play. Conditioning needs to be specific to the demands of tennis, rather than a general program that may be used by all types of athletes.**

- **Coaches should plan the athlete's playing schedule with recognition of the various periods of conditioning. Some of the periods may be short and some may be longer, but rest and recovery need to be included.**

- **Both strength and flexibility must be included in the conditioning program, and proper pre match warm up should be emphasized.**

- **A dynamic warm-up should be performed before each practice or competition. The USTA has developed a DVD on dynamic warm-up activities to aid coaches. In addition to the resources from the USTA, many doctors, physical therapists, certified athletic trainers, and strength and conditioning specialists have knowledge in these areas.**

The Effect of Racquets and Surfaces

Racquet characteristics and type of surface do have an impact on technique and injury risk, although the exact influence is hard to determine, since the body interacts with and can accommodate to both racquet and surface characteristics. Racquet characteristics are probably not primary determinants of injury risk.

Racquets

The characteristics of the racquet interact with the demands of tennis to also affect the loads on the hand, arm, and shoulder of the tennis player. These loads are determined by the incoming ball speed, the construction of the racquet, and how and where the ball impacts on the racquet. They are of three types- vibration, shock/jar, and twisting.

Vibration

There are 2 types of vibration caused by the interaction of the racquet and the ball.

1. The first type is **string vibration**. This type involves very little energy, and can be eliminated by the elastic damper devices in the string bed. Even without the damper devices, this is not a cause of pain or injury.

2. The second type of vibration is **oscillation of the racquet frame** itself. This type may involve high levels of resultant energy, is not affected by the elastic string

dampers, and it often requires significant muscle activation to withstand the energy produced. Several factors affect the amount of frame vibration and the load on the tennis player. It is minimized when the ball impact is at the “node” of oscillation, usually near the center of the strung region of the head. The stiffer the racquet frame, the smaller is the amplitude of the oscillation. The further the impact from the node, the larger the amplitude of the vibration. The harder the ball is hit, the larger is the amplitude of the oscillation and vibration. Gripping the racquet tighter decreases the time required to stop the oscillations, but the energy developed in the oscillations will be transferred as a higher load to the forearm muscles.

Shock and jar

When a tennis ball strikes a racquet, a force can be a felt by the hand and arm. This is related to the initial shock wave created by the impact. This force is of short duration, but can deliver a notable shock or jar to the hand and arm. To dampen this shock requires muscles to be activated and act as shock absorbers in the wrist and forearm. It is difficult for the player to distinguish between the effect of the vibration due to racquet oscillation and the shock/jar due to ball impact, and both can act to influence injury risk.

Some research has shown that the shock/jar is the primary cause of tennis elbow symptoms. Once again, the shock/jar is minimized when the ball impacts close to the center of the strung area of the head. Some variables that may reduce the amount of shock/jar felt by the player:

- An increase in dwell time (the amount of time the ball spends on the strings) results in a decrease in the average force experienced by the player. A reduction in string tension leads to an increase in dwell time and decrease in force.
- Gripping the racquet loosely prior to ball impact decreases the peak shock forces after impact.
- The stiffness of a racquet frame also may alter the shock/jar. A stiffer racquet, while providing more power, also transfers more shock/jar to the arm.

Off axis hits

Tennis strokes very commonly result in balls being hit away from the center axis of the racquet (mis-hits), causing the racquet to twist. This creates an “impulsive torque”, a rotational effect that is related to, but separate from, shock/jar. Muscle activation is also required to control this torque. The harder the ball is hit, and the farther from the main axis the ball is hit, the greater the twist and the resulting impulsive torque. This torque will occur even if the racquet is gripped firmly, and the transmitted force may be actually greater with a tight grip than with a loose grip. The main method to reduce twisting is to increase the diameter and weight of the racquet head. If the head diameter is increased by 25%, the stability factor against twisting will increase by 50%.

Coaching Applications

- **The racquet itself should not be thought of as the most important factor in tennis performance and injury risk. However, if injuries do occur, then part of the evaluation of the causation should focus on the type of racquet.**
- **The individual characteristics of a racquet do have a bearing on the power of the stroke and on the forces and loads that are transmitted to the hand and arm.**
- **However, the forearm and arm muscles have a large capacity to alter the effect of the racquet characteristics on body loading. The forearm and arm muscles have a large effect to dampen the vibration, shock/jar, and twisting, especially over the short term.**
- **The change in ball momentum (the power you get in the stroke) depends more on the racquet head velocity through the hitting zone than on the racquet head weight, size, or swing weight.**
- **With repeated loading in any or all of these directions, microtrauma and overuse injuries may occur.**
- **In general the player will feel less shock/jar from ball impact when using a heavier racquet, but this racquet will require more muscle activation to get it up to maximum velocity through the hitting zone. If injuries are felt to be due to shock/jar or twisting due to mis-hitting or poor technique, or due to playing more powerful opponents, then a heavier racquet with a larger head may be preferred.**
- **The player will usually generate more power by using a lighter racquet that may take less muscle activation to generate maximum velocity through the hitting zone. If the arm injury is felt to be due repeated use in many matches, then a lighter racquet may be preferred.**
- **In general, a racquet that has a larger head, is of moderate weight, is strung at moderate tension and is gripped loosely before and during impact combines the best characteristics to decrease the risk of injury from the interaction of the ball hitting the racquet.**

Shoe-surface interaction

Two properties of the court surface, friction and compliance, determine how a shoe and surface interact to generate or modify loads in the lower extremity.

- ***Friction*** relates to resistance to sliding or horizontal motion of the shoe against the surface.

- ***Compliance*** relates to the “softness” or vertical loading between the shoe and the surface.

Low friction surfaces allow the athlete to slide to a stop and have been shown to reduce the likelihood of traumatic injury to feet, ankles, and legs due to the more gradual dissipation of the forces generated in running, pivoting, and stopping. High friction surfaces allow more rapid stopping, changes in direction, and re-acceleration, but are associated with higher rates of traumatic injury. Surfaces with varying friction characteristics, such as a wet spot on a hard surface or the tape on a clay surface, may also cause injury due to the sudden change in friction load.

A more compliant “softer” court feels more comfortable to play on due to the decreased loading on the shock absorbing muscles in the legs. This type of surface is associated with a lower incidence of the overload types of injury. However, the compliant surfaces sometimes have higher friction characteristics.

As was seen with racquets, the effects of surfaces on injury and loads may be variable due to the athlete’s capability to adjust to the surfaces. Players can adjust to the surface compliance by changing landing and cutting strategies, and adjust to friction by sliding or not sliding into the shot. Studies have not shown markedly different loads in the legs between the different surfaces in well conditioned and skilled tennis players.

Coaching Applications

- **Shoes have been developed to help the athlete to run and stop on surfaces with different friction characteristics. The athlete should be guided to evaluate these types of footwear to see which will be the best for the particular surface. Information on fit, cushioning and support of the shoes should be integrated with characteristics of the player, style of play, and surface.**

- **It is important to teach good footwork technique for sliding on low friction surfaces and agility and landing on high friction surfaces in order to minimize the rapid development of high forces that may cause traumatic injury, and to maintain good conditioning of the legs to minimize overloads with repetitive use.**

The Relation of Technique to Injury

From a biomechanical and medical point of view, there is no one correct technique to hit a tennis shot. This is because the body is capable of putting the arm, hand, and racquet in the correct position with the correct velocity to impart force to the ball using any number different combinations of body movements, joint positioning and muscle activation. These body movement/joint position pathways determine the coordination used and loading in the body that could contribute to injury.

The Kinetic Chain

All body segments are linked to the rest of the body, meaning what happens in one part of the body impacts the forces and loads experienced by the rest of the body because the joints and muscles provide a mechanism to transfer energy throughout the body. This principle has been called the kinetic chain, where actions in one part of the body are transferred through a linked system to other parts segments. Optimal use of the kinetic chains in tennis requires less muscle activation, less load on the body structures, and less energy expenditure to achieve the desired result.

The optimal coordination of kinetic chains in high speed movement activities like tennis uses coordinated sequential movements of the segments of the body to build force from the ground through the hips and trunk to the shoulder and into the arm, hand and racquet. For example, approximately 50% of the energy needed to hit a forehand is generated from the legs and trunk and transferred through the kinetic chain to the racket. "Good" use of kinetic chains have common characteristics that allow them to be efficient, even though they may vary in overall appearance due to individual stylistic variations.

When these characteristics are not present, or the sequential timing is altered, the transfer of energy in the kinetic chain is said to be "broken". In a broken kinetic chain the energy that must normally be developed within many segments is altered and other body parts must make up for these changes when attempting to create the same performance. When the chain is broken, there is either a greater load placed on other body segments to achieve the desired result, or the athlete must accept a lower level of performance.

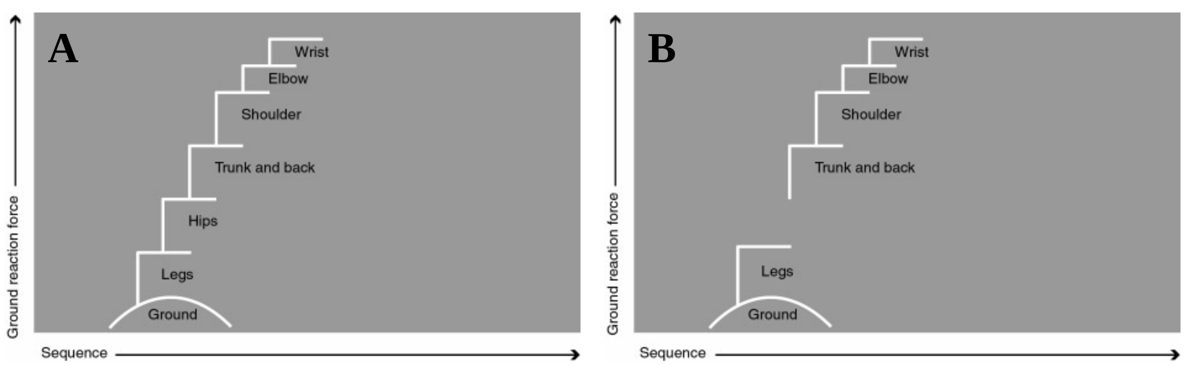


Figure A shows the normal kinetic chain, staring at the ground and proceeding through the legs, torso, shoulder, arm and finally to the racket. When a link is broken (Figure B), all of the energy and power generate below the broken link is lost and cannot contribute to power of the shot.

Example of How the Kinetic Chain is Used in Tennis

Serve

- **The player uses the ground reaction force as the base of the stroke.**
- **There is strong leg drive beginning with adequate knee bend.**
- **The hips and trunk have a counter rotation in cocking away from the court.**
- **The scapula and shoulder move together to reach a position of maximum external rotation in cocking.**
- **The arm exhibits long axis rotation, which is a coupled motion including shoulder internal rotation and forearm pronation.**

Forehand

- **Ground reaction force as the base of the stroke.**
- **Strong leg drive off the back leg.**
- **Trunk rotation around the back leg.**
- **Long axis rotation of the entire arm so that the elbow points towards the path of the hit ball.**

Backhand

- **Strong leg drive off the back leg.**
- **Trunk counter rotation away from the court.**
- **For the 1-handed backhand, trunk and front shoulder rotation into the shot.**
- **For the 2-handed backhand, trunk rotation into the shot.**

There are many examples of kinetic chain breakage in tennis players. For example:

- If the knees are not bent more than 10 degrees in the serve cocking phase, it places a 23% greater load on the shoulder and 27% greater load on the elbow to achieve the same serve velocity.
- If the hips don't counter rotate and then rotate into the serve, it requires 28% more load in the elbow to achieve the same ball velocity.
- If the trunk does not rotate to provide force to the shoulder, it requires a 34% increase in shoulder velocity to achieve the same ball velocity.
- The motion that helps to protect the elbow against the loads in the serve is generated by the long axis rotation of the arm and shoulder rotation. If long axis rotation is not present, the forearm muscles would have to be 60% larger in size than they are to protect the elbow against injury, either on the medial (inside) or lateral (outside) areas.

Evaluating Strokes

Coaches will be able to observe these outward manifestations of kinetic chain breakage as they watch the players hit the strokes. One way to analyze technique is for the coach to concentrate on one aspect of the kinetic chain (knee bend, hip counter rotation, shoulder cocking, elbow motion etc) in each stroke, to see if the kinetic chain in that area is intact. With subsequent strokes, he or she can look at another area, and then the stroke may be evaluated as a whole. By this method of evaluation, the reason behind the poor technique may be determined, and corrective measures or other interventions may be prescribed (e.g. stroke alteration, conditioning, drill adjustment). A good reference for this type of evaluation is the book by Knudson and Morrison.

Coaching Applications

Kinetic chain breakage is usually manifested and observed as "poor technique". Some of these common technique errors include:

- **Excessive cocking of and subsequent motion of the wrist in the forehand or backhand. This is due to decreased trunk rotation in to the shot, so the player uses more wrist motion to hit the shot. This will place increased loads on the wrist tendons and cartilage.**
- **Leading with the elbow, either on the forehand or the one-handed backhand. The trunk and shoulder are not delivering enough force to the elbow and arm, so the player compensates with elbow muscle activation. This will cause medial or lateral tennis elbow.**
- **"Short arming" the shot on the forehand. There is no long axis rotation, so the elbow faces away from the path of the ball and the hand does not end wrap around in the follow through.**
- **Hitting the groundstrokes "late" or behind the body. Either mistiming the initiation of the stroke or lack of sufficient leg drive does not allow normal motion of the racquet into the hitting zone.**
- **"Pull through" on the serve. There is decreased leg contribution to the kinetic chain, so instead using the leg muscles to "push" from the ground up into the trunk and arm through the serve motion (leg drive), the player uses the smaller trunk muscles to "pull" the arm through the serve motion. This can be seen by the coach as a lateral lean of the trunk into the serve and as minimal hip and trunk counter rotation in cocking. This motion places excessive loads on the trunk muscles, shoulder, and wrist as they try to compensate.**
- **Stiff legged serving. This occurs with minimal knee bend into the cocking phase of the serve, and creates the excessive loads in the shoulder and elbow.**

Useful References for Coaches

1. Elliott B, Pluim B, Kibler B (eds) *Journal of Science and Medicine in Sport* March 2003, volume 6.
   This entire volume of this medical journal is devoted to tennis specific research. There are articles on kinetic chain breakage, adaptations to tennis play, fluid requirements, and technique effects on shoulder and arm loading.

2. Kibler WB, Chandler TJ. Sport specific conditioning. *American Journal of Sports Medicine* 1994, volume 22, pp 424- 433
   This paper provides an overview of periodization and conditioning techniques and suggests a periodized tennis specific conditioning program.

3. Kibler WB, Safran M. Musculoskeletal injuries in young tennis players. *Clinics in Sports Medicine* 2000, volume 19 pp 781- 793.
   This paper reviews all the injury data in young tennis players.

4. Knudson D, Morrison C. Qualitative Analysis of Human Movement 2nd Edition Human Kinetics 2002
   This book reviews research on the systematic observation, evaluation, diagnosis And intervention to improve human movement. Several examples are developed, including tennis serving

5. Knudson D, Elliott B. Biomechanics of tennis strokes. In *Biomedical Engineering Principles in Sports*. Pp 153- 181. Kluwer Academic/Plenum Publishers 2004
   This chapter reviews the biomechanics of tennis techniques and illustrates how coaches can use this knowledge to analyze strokes.

6. Nigg B, Sagesser B. The influence of playing surfaces on the load on the Locomotor system and on football and tennis injuries. *Sports Medicine* 1998, volume 5, pp 375- 385.
   This paper reviews research on injury rates and surfaces, with a major emphasis on tennis

7. Roetert P, Groppel J (eds) World Class Tennis Technique Human Kinetics Publishers 2001.
   This book reviews all aspects of biomechanics and coaching in tennis. Each chapter is co-written by a tennis coach and a scientist, so both viewpoints are presented.

8. Renstrom P (ed) IOC Encyclopedia- Tennis Blackwell Publishers 2002
   The tennis issue in the International Olympic Committee Medical Commission series on medical problems and sports science. The book reviews biomechanics, equipment, injuries, rehabilitation, and conditioning.