LOADING IN TENNIS STROKE PRODUCTION

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The goal of analyzing the loads associated with tennis stroke production is optimizing tennis performance, while at the same time minimizing the risk of injury. Thus, important issues may include: how the power of a stroke is produced; how the loads are generated and transmitted and how improper techniques would increase the risk of injury. These issues are discussed with particular reference to the tennis backhand and tennis elbow.

KEY WORDS: tennis, tennis elbow.

INTRODUCTION: The power of a tennis stroke is characterized by the velocity of the centre of the racquet-head at impact. For forehand and backhand drives, the velocity component perpendicular to the plane of the racquet-head is critical in effective stroke production. For forehand and backhand topspin and backspin strokes, both the velocity component perpendicular to the plane of racquet-head and the velocity component tangential to this plane are important. Thus, a basic question regarding the stroke production is *how the velocity of the centre of the racquet head, is generated*.

If the arm-hand-racquet system is simplified as a three rigid body system (Sprigings et al. 1994), the velocity of the centre of the racquet-head is determined by the relative rotational movements of seven rotational (angular) velocity components, as well as the velocity of the centre of the shoulder joint. The seven rotational velocity components are:

- shoulder internal/external rotation, flexion/extension and abduction/adduction
- elbow flexion/extension and supination/pronation
- wrist flexion/extension and ulnar/radial deviation

The velocity of the centre of the shoulder joint, as a vector, is determined by the rotational velocity of the trunk and the velocities at the centres of the two hip joints (to be precise, the rotation of the trunk is not a rigid body). The velocities at the centres of the two hip joints are determined by the various rotational velocities in the lower extremities. Thus, the power of a stroke is the summation of movements of all body segments from the feet, through legs, trunk and the arm, to the hand-racquet. This is called the kinetic chain (Kibler et al., 2004).
In a powerful tennis stroke, the stretch-shortening cycle (SSC, cf. Komi, 1992) occurs about various joints for the majority of segment movements involved in the kinetic chain. During the stretching phase, elastic potential energy is stored in the agonist muscle. This is at least in-part released in the shortening phase and assists the relevant segment reach a higher speed than if a purely concentric action of the agonist muscle occurred without a preceding stretching phase. For this purpose, the stretching phase has to be short as if this period is extended the visco-elasticity of the muscle would dissipate the elastic potential energy into heat. For the movements of the arm-hand-racquet system in tennis strokes, the SSC occurs along the whole kinetic chain, including the shoulder, the elbow and finally the wrist.

DETERMINATION OF LOADS IN TENNIS STROKE PRODUCTION: During tennis stroke, the loads imposed on each body segment at each joint, and the loads on each group of muscles, are determined not only by external impacts (the ball and the ground), but also by the motions of all body segments in the kinetic chain. In order to understand this concept, the *Linear and Angular Momentum Theorems* must be understood. These are based on Newton's Second law, and are simply defined as:

(A) The product of the mass of the segment and the acceleration of the centre of mass of the segment is equal to the sum of all the forces acting on this segment *(Linear*).

(B) The product of the moment of inertia of the segment and the angular acceleration of the segment is equal to the sum of all torques acting on the segment (*Angular*).

The moment of inertia is related to the mass distribution of the segment and characterizes the ability to resist the change of rotational velocity. Acceleration and angular acceleration are the rate of change of velocity and the rate of change of angular velocity respectively (cf. Elliott et al., 2003). If the motion of a segment is known, and the loads (force and torque) acting on this segment at one end are also known, then the loads (force and torque) acting on this segment at the other end can be determined by the above statements (A) and (B). Typically the force and the torque at one end of a segment are obtained from a neighbouring segment. According to the third Newton's law, the neighbouring segment would suffer from the same force and torque as it gives to this segment but with opposite signs. By repeating this procedure, the loads acting on all body segments at all joints can be determined, segment by segment. This process reveals how the loads are generated and transmitted from one segment to the next.

Actually, there are an infinite number of possible kinetic chains, which would result in the same velocity of the centre of the racquet-head. For a well-trained tennis player, a successful stroke is associated with an optimal or near optimal kinetic chain. In this chain an optimal or near optimal power of the racquet is reached and the loads are reasonably distributed on different body segments, at different joints, among different groups of muscles. In contrast, poor coordination of different body segments would cause disruption of the kinetic chain (Kilber et al., 2004), leading to overloads on some muscles and tendons – increasing the risk of injury. The most common tennis injury for recreational players is tennis elbow, which is a kind of tendonitis (inflammation of a tendon) at the epicondyle(s) (the bony prominence of the humerus, where the forearm tendons attach) and is therefore called epicondylitis. This could happen on the outside (called lateral epicondylitis) or on the inside (called medial epicondylitis) of the elbow. The condition is 5 times more common on the lateral side than on the medial side.

HOW DO THESE LOADS APPLY TO GROUNDSTROKES IN TENNIS?: Backhand compared with forehand strokes: Why is tennis elbow mostly caused by improper backhand strokes? For forehand strokes, it is easier for the striking arm to move back and forth (backswing and forwardswing). Powerful elements of the kinetic chain also may be used to link the lower and upper body (e.g. via rectus abdominis - the large muscle of the abdomen). So it is easier to produce energy by coupling a quite large number SSC to result in optimal shoulder and the elbow movements. Thus, the shoulder and the elbow rotations are able to make a large contribution to the production of the power of the forehand stroke. These contributions are important because the distances from the shoulder and the elbow to the impact point on the racquet-head are much larger than the distance from the wrist to this point. Thus, a given rotational (angular) velocity at the shoulder or at the elbow would result in much larger linear velocity at the impact point than the same angular velocity at the wrist. In other words, the rotations at the shoulder and at the elbow are more efficient in producing the power of stroke among the seven rotations of the arm-hand-racquet system (Yue et al., 2001). However, for backhand strokes, the backswing of the striking arm can not reach as far as in forehand strokes if the rotation of the upper body reaches the same angular range. Therefore, SSC can not fully take place for the rotations at the shoulder and at the elbow. Thus, the production of power in the backhand relies heavily on movements at the wrist.

In the final analysis, we have not evolved to play tennis. The strength distribution of human muscle-tendon system is the result of evolution of millions years to meet the needs and the physical demands of everyday life. When we push, pull or carry an object, we typically need muscles that allow shoulder flexion or extension. These high demands result in strong biceps and triceps muscle groups respectively. In contrast, we seldom need fast wrist extension and forearm supination in everyday life and in physical labour. Perhaps the only cases requiring fast wrist extension and supination are the racquet sports (tennis, table-tennis and badminton). Thus, if the relatively weak wrist extensor is overused by improper backhand stroke techniques, some injury of the related muscle and tendon may occur (cf. Roetert et al., 1995).

There are various conditions in backhand strokes, which may cause tennis elbow:

- The strings are too tight: The tighter the strings, the shorter the contact time and therefore the larger the impact force. Thus, too tight strings may cause overload on the wrist extensors during the backhand stroke.
- Off-centre hit: If the impact point is away from the central axis of the racquet, a twisting torque is then generated, in addition to the normal impact force. The elbow pronator/supinator muscle groups would then be loaded and would react *passively* because this twist is not expected by the player. This passive reaction would also be a disturbance to the wrist extensors, so these may not be as well coordinated as in the case of central hit. An off-centre hit thus would generate an extremely “short” SSC (less than 50 ms) that would lead to a very high tension in the respective tendon. An overuse of the extensor carpi radialis brevis attachment is generally given as the major reason for tennis elbow. In addition, an off-centre hit causes larger vibrations after impact (Elliott et al., 2003). These vibrations may be transmitted to the elbow and impose additional loads to the related muscles and tendons.
- Too small racquet head at impact: The smaller and the lighter the racquet head, the smaller is the polar moment of inertia of the racquet-head, and therefore there is less resistance to an off-centre impact.
- Heavy (say wet) ball: That would increase the impact force and the load on the wrist extensor.
- Racquet almost perpendicular to the forearm: This would cause a strong twisting torque on the forearm and a high load on the supinator muscle group.
- Too late hit an impact - not hitting the ball in front: Under this condition, SSC can hardly reach its optimum for the rotations at the shoulder and at the elbow. Thus, the rotations at the shoulder and at the elbow can not contribute optimally to the generation of the power of the stroke. Therefore, too much load will be imposed on the wrist extensor musculature.

The following recommendations could be made:

- Two-handed instead of one-handed backhand stroke: Players sensitive to tennis elbow should use a two-handed backhand, where at least part of the impact force will be transmitted to the supporting arm. This will greatly reduce the load on the forearm of the striking arm. With the two-handed grip, the wrist extension of the striking arm can not work as fast as in the one-handed stroke. In order to produce the desired power of backhand stroke, the trunk rotation and the shoulder rotations have to make larger contributions than in the one-handed backhand stroke. This would also reduce the load on the wrist extensor. In addition, for off-centre hit, the twisting torque will be partly balanced by the wrist action of the supporting arm. Thus, the load transmitted to the pronator/supinator musculature of the striking arm and the possible influence to the wrist extensor would be greatly reduced. Indeed, players with two-handed backhand have a very low incidence of tennis elbow (cf. Roetert et al., 1995).
- Players should perform strength training, especially reactive strength, particularly for the muscles governing the forearm and wrist movements. A stronger wrist extensor and supinator musculature would enable larger loads to be transmitted to the system without overload.

- Players must always be conscious of proper technique (see previous section).
- Choose the appropriate racquet (cf. the last section).

For similar reasons, court surface with proper friction and softness will help to reduce the risk of injuries to the lower extremities.

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