.....

Tennis Injuries

W. Ben Kibler^a, Marc Safran^b

^aLexington Sports Medicine Center, Lexington, Ky.; ^bDepartment of Orthopedic Surgery, University of California, San Francisco, Calif., USA

Abstract

Objective: The purpose of this chapter is to critically review the existing studies on the epidemiology of tennis injuries in pediatric athletes, present suggestions for the prevention of injury based on these studies, and present suggestions for future research. **Data sources:** Data sources included published articles on pediatric tennis injuries, a previously published review by the authors, and unpublished data from one of the authors (MS). **Main results:** Most studies of tennis injuries show that they are of microtrauma origin, develop over time, and result in short times of absence from play. They involve all joints of the body, but have a higher incidence in the shoulder, back, and knee. Intrinsic and extrinsic risk factors may be related to the incidence of injury. These factors may be evaluated by a comprehensive preparticipation exam, and preventive strategies may be implemented. **Conclusions:** Most injury studies in pediatric tennis players vary in the population studied, methods of injury evaluation, and risk factors studied. Consequently, few specific conclusions can be derived about the causative factors. Further longitudinal prospective studies need to be done to completely discover all the factors involved in producing tennis injuries.

Copyright © 2005 S. Karger AG, Basel

Introduction

The recreational pediatric tennis player experiences relatively few major or minor injuries. The frequency and duration of play and the biomechanical and physiological loads inherent in tennis at this level are low enough to allow safe play. However, if the pediatric athlete is engaged in intense participation in tennis alone or in tennis combined with other sports, injuries occur with increasing frequency [1, 2]. This is a consequence of increased frequency and intensity of play, increased duration of play, the large inherent biomechanical and physiological demands at this level of play, and the deleterious effects of maladaptations in flexibility and strength that occur in areas subject to repetitive tensile

overload [3] and in association with normal growth. These injuries become a limitation to successful play. This chapter will review the available studies and discuss the epidemiology of injuries in elite pediatric tennis players.

The database for this review was mainly from published sources in the sports medicine literature and a previously published review by the authors. Some of the data is in unpublished form, resulting from one of the authors' (MS) use of a validated questionnaire at age group national tournaments. The database included publications from the last 18 years. Most of the studies involved athlete responses to directed questions or to questionnaires, so there was a level of reporting bias. The definition of injury varied between the studies. There were several studies of injury incidence that were prospective in nature, but no long-term prospective studies relating specific anatomical, physiological, biomechanical, or playing factors to injury incidence. The result is that the literature provides glimpses into types of injuries and suggests associations of certain physiological parameters and injury, but does not provide conclusive evidence of cause/effect relationships, or of conclusive benefit of any specific intervention strategies.

Incidence of Injury

The incidence of injury in tennis is a bit elusive. Only a few studies have been performed attempting to identify this information. Table 1 summarizes the incidence and prevalence of injuries in pediatric tennis players [2, 4–9]. One study [4] of college age tennis players is included to show the injuries in a group with similar playing exposure but slightly older age. A review of this table reveals that most of the studies used the prospective cohort design. Study duration ranged from one to 8 years and the sample size varied widely, from 23 to 1,440. Also, data collection methods and injury definitions varied among the studies. Injury rate definitions also varied, ranging from any injury resulting in not playing to injuries that required a medical evaluation. In general, injury rates were relatively low, from two to twenty injuries per 1,000 athletic exposures or hours played.

During the 1998 USTA Girls' 16's and Boys' 16's and 18's National Championships, Safran et al. [5] administered a validated tennis questionnaire to assess the prevalence of injury in these elite junior players. Only 23% of girls and 45% of boys reported no injury that kept them from playing for one week or more, while 53% of females and 29% of males noted more than one tennis injury in the past. The findings in this study have been reproduced in two other unpublished studies of different tennis tournaments by the same authors [Safran 1999, unpubl. study; Hutchinson 1999, unpubl. study].

Table 1. Injury incidence

Study	Study design	Data collection methods	Duration of study	Number of subjects	Number of injuries – acute	Injury rate – acute
Hutchinson et al., 1995 [2]	Prospective cohort design	Injuries seen/evaluated by trainer or MD during annual National Championships	6 years	1,440	143	9.9/100 athletes 21.5/1,000 athletic exposures
Hutchinson 1999 [unpubl. data]	Prospective cohort design	Injuries seen/evaluated by trainer or MD during annual National Championships	4 years	960	122	12.7/100 athletes 2.8/1,000 athletic exposures
Safran 1999 [unpubl. data]	Prospective cohort design	Injuries seen/evaluated by trainer or MD during annual National Championships	4 years	741	77	10.4/100 athletes 1.9/1,000 athletic exposures
Winge et al., 1989 [7]	Prospective cohort design	Injuries sustained during 1 season	1 year	89	46	0.52 injuries/player/season; 2.3 injuries/player/1,000 h
Silva et al., 2003 [8]	Prospective cohort design	Injuries seen/evaluated by PT, trainer or MD during 13 tournament junior tennis season	1 year	258	151 players injured 272 injuries	1.8 treatments per injured player 6.9 evaluations per 1,000 games played
Lanese et al., 1990 [4]	Prospective cohort design	Weekly chart review of all injuries seen by trainer (attending each practice/competition) – university with loss of any time	1 year	23	10	43 injuries per 100 players 0.14 injuries/100 person-hours

Table 1 (continued)

Study	Study design	Data collection methods	Duration of study	Number of subjects	Number of injuries – acute	Injury rate – acute
Beachy et al., 1997 [9]	Retrospective cohort	Injuries that resulted in missed practice or play recorded by school trainer	8 years	588	146	0.35 injuries per female; 0.14 injuries per male player
Reese et al., 1986 [6]	Retrospective cohort design	Australian Institute of Sport review of medical records	4 years	45	176	0.06 injuries/ player/year
Safran et al., 1999 [5]	Case-control design	Injuries seen/ evaluated by trainer or MD during annual National Championships and prospective validated questionnaire	2 years	851		13.3/100 athletes 2.9/1,000 athletic exposures

Injury Characteristics

Injury Onset

The most common types of injury in young tennis players are microtrauma-related overuse injuries [2, 3, 5–9], particularly to the upper extremity. Examples of overuse injuries include rotator cuff tendinitis, epicondylitis, chronic muscle strain, growth plate injuries, and stress fractures. Other injuries are the effects of single incidents of trauma, such as ankle sprains, abrasions, contusions, and fractures. The greater percentage of these is to the lower extremity, particularly the ankle.

Injury Location

Table 2 summarizes the location of the injuries in pediatric tennis players [2, 6, 7, Safran 1999, unpubl. study; Hutchinson 1999, unpubl. study]. The data are usually presented as a percentage of total tennis injuries. The data may be divided into general body areas, or by anatomic areas such as joints or areas. In general, the lower extremity as a whole experienced the highest percentage

Table 2. Injury location

	Hutchinson 1995 [2]	Hutchinson 1999 [unpubl. data]	Safran 1999 [unpubl. data]	Winge 1989 [7]	Reece 1986 [6]
<i>Central</i>	24.6%	30.5%	21.3%	11%	21%
Head/Neck	15.4	15.1	20	—	2.7
Back	65.4	52.8	56.7	100	70.3
Abdomen	11.5	18.9	16.7	—	18.9
Groin	7.7	11.3	6.7	—	8.1
<i>Upper extremity</i>	26.5%	30.5%	27.7%	45.7%	20%
Shoulder	25	47.2	38.5	38.1	45.7
Elbow	44.6	28.3	17.9	33.3	34.3
Wrist	14.3	17.0	30.8	4.7	20
Hand	16.1	9.4	12.8	23.8	—
<i>Lower extremity</i>	48.8%	39.1%	51.1%	39%	59%
Hip	12.6	14.7	12.5	—	6.7
Thigh	25.2	29.4	16.7	11.1	16.3
Knee	12.6	14.7	9.7	16.7	22.1
Leg/Calf	6.8	8.8	18.1	22.2	16.3
Ankle	23.3	22.1	16.7	27.8	25
Feet	20.4	10.3	26.4	22.2	13.5
Other	—	—	—	4.3%	—

of injuries, ranging from 39 to 59% of the total, followed by the upper extremity, 20–45%, and the central core, 11–30%. Of the specific anatomical locations, the ankle and thigh showed the highest frequency in the lower extremity, the shoulder and elbow showed the highest frequency in the upper extremity, and the low back was highest in the central core.

In tennis, the repetitive nature of high-velocity arm movements causes overuse injuries in the upper extremity while the sprinting, stopping and pivoting, and pounding motions place repeated rotational shear and loading forces on each joint of the lower extremities which, in turn, places the athlete at increased risk for acute and overuse injury. In children, the growth plates, particularly the apophyses, are susceptible to stress injuries as they undergo ossification, resulting in local inflammation, disordered or irregular ossification patterns, overgrowth, and pain. This is important because a forceful acute injury in the milieu of weakness and disordered ossification from recurrent microtrauma may result in small avulsion fractures at the apophysis [10].

Situational

No data currently exist as to when during practice or play or in what phase of the tennis year most injuries occur. Since the majority of injuries are musculotendinous, however, it is commonly found that acute muscular strains occur early in practice or play, usually associated with improper warm-up, or late in practice/play due to muscular fatigue.

Action or Activity

There are no published data that identify rates of injury based on the activity engaged at the time of injury. However, different strokes have been suggested to place greater risk to areas of the body that may result in injury. It has been shown that the median and peak muscular activity levels in the shoulder and forearm muscles of adult tennis players are higher during the service action than during other strokes, indicating that serve is the most strenuous stroke in tennis [11], and it is presumed that the same type of loading occurs in the similar strokes executed by pediatric players. There is also a suggestion that the abbreviated service motion may place additional loads on the shoulder and elbow in the tennis swing [11].

Additionally, style of play – serve and volley or baseline play – may also be associated with injury rate, although Safran et al. [5] found no statistical evidence to confirm this. However, it was shown that there was a higher rate of abdominal, groin, hip, thigh, and shoulder injuries in males, where approximately 12% of boys stated being serve-and-volley players and 68% noted being all-court players. Females, however, reported 58% were all-court players with 1% of females playing serve and volley-style tennis [5]. This less aggressive style of play for females may account for the difference in types of acute muscular injuries; however, again, the numbers were not large enough to show a statistical significance.

Chronometry

Junior tennis players play a disproportional amount of tennis during summers and holidays, when school is out. Most national tournaments occur during summers and holidays as well. Though not studied, it would be intuitive that the injury rates for young tennis players might be increased during these times.

Injury Severity

Injury Type

Table 3 shows data relating to injury type [2, 6, 7, 8, Safran 1999, unpubl. study, Hutchinson 1999 unpubl. study]. Perusal of this table reveals that the

Table 3. Injury type

	Hutchinson 1995 [2]	Hutchinson [unpubl. data]	Safran 1999 [unpubl. data]	Silva 2003 [8]	Winge 1989 [7]	Reece 1986 [6]
Sprains	17.1	8.6	8.5	—	17	—
Strains	55	64.9	54.6	39.6	14	—
Contusions	3.8	2.9	5.0	4	—	—
Abrasions	7.6	2.3	0	—	5	—
Lacerations	1	0.6	0	—	—	—
Fractures	1	0.6	0.7	—	2	—
Dislocations	0.5	0	0.7	—	—	—
Inflammation	10	14.9	18.4	17.7	—	—
Miscellaneous	3.8	5.1	12.1	—	—	—
Overuse	—	—	—	—	67	28.4%

most frequently occurring injury type in these studies was strain (range = 14 to 64.9%), followed by inflammation (range = 10 to 18.4%), then sprain (range = 8.5 to 17.1%). Many strains could be classified as either traumatic or overuse, depending on how long the symptoms persist, or how suddenly the symptoms appeared. Strains are the most common individual type of injury, ranging from 14–64.9%. Common injuries in tennis are listed by the region of injury.

Shoulder

The shoulder girdle is especially prone to injury because it has to maximally accelerate and decelerate the arm while maintaining precise control over the racquet at ball strike. The shoulder is the most frequently affected part of the upper extremity with incidence between 25 and 45.7% (Table 2). Rotator cuff inflammation is one of the most common injuries in tennis players. Lehman [12] found that 24% of junior tennis players complained of shoulder pain currently or in the past. In a survey of participants in the 1998 USTA Girls' 16's National Championships, 35% noted shoulder pain currently or in the past (56% of these were anterior shoulder pain, 15% posterior shoulder pain, and 31% both anterior and posterior) [5]. Of the 16- and 18-year-old participants at the 1998 USTA Boys' National Championships, 25% noted previous or current shoulder pain (38% anterior shoulder pain, 30% posterior shoulder pain, and 32% noted both anterior and shoulder pain) [5].

In the young player, rotator cuff symptoms are often secondary to instability of the glenohumeral joint [13]. Instability may result in labral degeneration or tears. Other shoulder injuries include humeral periostitis and bicipital tendinitis. Less common shoulder injuries may occur to the growth plates. This includes traction apophysitis, an overuse injury caused by repetitive microtrauma at the

insertion of the supraspinatus muscle into the greater tuberosity, or the subscapularis muscle into the lesser tuberosity of the humerus. Proximal humeral physeal injury and slipped capital humeral epiphysis may also occur [10, 13].

Acute shoulder injuries are uncommon in tennis, though shoulder dislocations and acromioclavicular joint separations may occur from a fall.

Elbow

Lateral epicondylitis (tennis elbow), medial epicondylitis, and injury to the medial epicondylar apophyseal growth plate in skeletally immature players are common injuries about the elbow seen in tennis players. These injuries are associated with chronic repetitive overload. On the lateral aspect of the elbow, epicondylitis involves the extensor carpi radialis brevis but may involve the entire lateral mass. Lateral epicondylitis occurs more frequently in recreational tennis players, particularly those with poor mechanics of the backhand. Medially, the medial epicondylar growth plate, the flexor mass, or the medial collateral ligament might be involved [10]. Medial epicondylitis occurs much less frequently than lateral epicondylitis, though it tends to occur in higher level tennis players. It has been noted that the frequency of tennis elbow in world-class athletes ranges from 35-45% [14]. This frequency is much lower in elite junior athletes [2, 7]. In addition, small avulsion fractures may occur because of the anatomy of the adolescent elbow. Nonunion of the medial or lateral epicondyle has rarely been seen. Ulnar collateral ligament injuries in the tennis player are uncommon.

In the author's survey of participants in the 1998 USTA Girls' 16's National Championships, 25% noted elbow pain currently or in the past while 22% of participants at the 1998 USTA Boys' National Championships reported previous or current elbow pain [5].

Hand and Wrist

Hand and wrist complaints are common in tennis players, especially females. Further, nondominant wrist pain is common in players using two-handed backhands. In the study of participants in the 1998 USTA Girls' 16's National Championships, 29% noted dominant wrist pain and 25% noted nondominant wrist pain currently or in the past [5]. For the male participants at the 1998 USTA Boys' National Championships, 19% noted previous or current dominant wrist pain and 6% noted nondominant wrist pain [5].

Tendinitis of the wrist may develop in elite players who place a lot of spin on their shots or in novices with mechanically improper technique. Wrist extensors are most frequently involved, but flexor tendons may be involved as well. Extensor carpi ulnaris tendinitis is primarily due to overuse or technique flaws and often is associated with triangular fibrocartilage tears or ulnocarpal impingement. It is often seen in the nondominant wrist of players with

two-handed backhands, possibly due to the overuse during the backswing. Extensor digitorum communis tendinitis, particularly to the index and little fingers due to their oblique course across the wrist, is often seen in tennis players. Tendinitis of the extensor pollicis longus uncommonly occurs in tennis players as the tendon passes Lister's tubercle. An occult dorsal ganglion is a common cause of radial wrist pain in the tennis player.

Recurrent dislocation of the extensor carpi ulnaris tendon has been reported in tennis players associated with hypersupination and ulnar deviation, such as with a backspin slice or low forehand or slice or topspin service motion [5]. Other, less common causes of wrist pain include a fracture of the hook of the hamate (from abutment with the bottom of the grip), injury to the triangular fibrocartilage complex, ulno-carpal impingement, chondromalacia of the pisiform, ulnar nerve compression in Guyon's canal, ulnar artery thrombosis, median nerve entrapment in the carpal canal, and triquetrolunate ligament injury. Wrist fractures and dislocations have also been reported from falls in tennis.

Forearm

Stress fractures of the ulna of the nondominant forearm in adolescents, as well as distal radius and ulna fractures of the dominant wrist, have been reported in the tennis player with forearm and wrist pain [10]. These injuries to the nondominant forearm occur in players who use a two-handed backhand.

Central Region Injuries (Back and Trunk)

In the elite junior tennis survey, 47% of females and 31% of males noted low back pain currently or in the past [5]. Various studies have found that up to 50% of randomly selected elite adult players had a history of low back pain of at least one week's duration [15, 16].

There are a variety of sources of low back pain in the tennis player. High demands placed on the lower back and trunk combined with low flexibility patterns result in frequent overuse-type injuries [17]. Other potential causes of low back pain include intervertebral disc degeneration and herniation, facet impingement, and spondylosis due to the repetitive hyperextension and rotation of the spine.

Injuries to the abdominal muscles are usually acute strains that occur during serves, particularly to the nondominant rectus abdominus muscle and obliques. Open-stance forehand strokes are purported to be the cause of the increasing incidence of abdominal muscle injury as well.

Hip/Thigh

The most common areas for strains in the thigh are the adductor muscles (groin pulls) and the hamstrings. Adductor muscle strains usually result from

sudden changes in direction, particularly when attempting to stop lateral movement by sliding or posting the lead foot. Slipping on clay courts, resulting in 'the splits', may also strain the adductor muscles. Hamstring tears may occur at either end of the muscle and are usually associated with explosive acceleration, for example, when sprinting or charging towards the net. Hip flexor strains are not as common in the young tennis player. Quadriceps strains may occur when a player slides on clay courts with the knee flexed and then the player tries to forcefully extend the knee.

Knee

Statistics from the USTA national teams show that 19% of all injuries are knee injuries with 70% of the injuries being traumatic and 30% overuse. The patellofemoral joint is susceptible to overload and overuse injuries. This may be commonly manifested as Osgood-Schlatter's syndrome (tibial tubercle apophysitis) in young racquet sports players, patellar (jumper's knee) and quadriceps tendinitis in skeletally mature individuals, and patellofemoral syndrome or chondromalacia patellae [18].

Acute knee injuries, such as knee sprains and meniscal tears, are not particularly common but can occur secondary to the twisting demands of the sport on the knee [19]. Medial collateral ligament injuries are the most common injuries, though ruptures of the anterior cruciate ligament have been reported. Patellar dislocations have also been documented in tennis, racquetball, and squash.

Less common causes of knee pain in tennis players include prepatellar bursitis, pes anserine tendinitis, semimembranosus tendinitis, and iliotibial band syndrome.

Leg

Muscle cramps of the calf are very common in tennis. Gastrocnemius muscle strains are common and occur during repeated, explosive accelerations of the leg, such as while sprinting or jumping. These strains and injuries to the Achilles tendon occur when a foot that has been plantarflexed is suddenly forced into dorsiflexion while the knee is in full extension. 'Tennis leg' is described as a strain or partial tear of the gastrocnemius at its medial origin and is uncommon in the pediatric tennis player. Less commonly, soleus injuries may occur and are seen with sliding on clay courts with extreme ankle dorsiflexion with concurrent knee flexion. Achilles tendinitis and calcaneus apophysitis (Sever's apophysitis) may be seen in pediatric athletes, including tennis players [20]. Shin splints, periostitis, is an overuse injury seen frequently in tennis, particularly when played on hard courts. Stress fractures of the tibia and of the distal fibula also infrequently occur in tennis players.

Ankle

Ankle sprains are the most common macrotrauma injury in tennis due to the frequent running and pivoting, stopping and starting movements as well as lunging and jumping. As a result, high twisting forces result about the ankle. Most injuries occur during twisting while the ankle is in plantarflexion, resulting in lateral ankle sprains.

Foot

Foot injuries in tennis players may include stress fractures, plantar fascitis, and 'tennis toe'. Stress fractures are most common at the base of the fifth metatarsal and the metatarsal diaphysis. Tennis toe is an injury to the great toe or second toe due to impaction of the toe onto the toe box of the shoe. The impaction of the toe onto the anterior aspect of the shoe can lead to subungual hematomas, nail bed injuries, or to 'jammed' joints at the distal interphalangeal, proximal interphalangeal, or metatarsophalangeal joints.

Time Loss

Most of the data reporting injuries in tennis are for players seeking evaluation of medical problems [6, 8, 17]. Other studies have defined injury as missing part of practice or play [2, 4, 5, 7, 9]. Unfortunately, with so few epidemiological studies, including no studies looking specifically at the relative distribution of injuries based on time lost from tennis, no meaningful conclusions can be based on existing literature regarding time loss from play.

Long-Term Effects

The residual effects of injuries related to tennis are unknown. However, some logical outcomes may be hypothesized. With regard to chronic rotator cuff inflammation, there is the potential of accelerated rotator cuff degeneration and tearing. Tennis shoulder refers to the combination of a protracted scapula, excessive glenohumeral internal rotation, and weak muscles which produce a drooping, internally rotated shoulder, which may contribute to generalized laxity of the shoulder capsule and musculature. This is more common in professional players or those who have played for many years. This may potentiate rotator cuff pathology due to the protracted scapula not allowing the acromion to rotate sufficiently out of the way from the greater tuberosity.

Lateral epicondylitis (tennis elbow) is associated with chronic repetitive overload. Though its name suggests inflammation, microscopic examination suggests that inflammation is not really involved. Repetitive microtraumatic injury is felt to result in microtears of the muscular origin. Focal degeneration and healing with vascular and fibroblastic proliferation suggests that this is a degenerative process. It does appear that the elbow is prone to further injury

with long-term use. It has been noted that an incidence of tennis elbow in world-class athletes ranges from 35 to 45% [14]. This incidence is much lower in elite junior athletes supporting the opinion that tennis elbow is related to age.

There are no studies evaluating the long-term effects of playing tennis. Many professional players have retired due to chronic low back pain. Sward [16] found 50% of randomly selected elite players had a history of low back pain of at least one week's duration, and 46.7% had abnormal radiographs of the lumbar spine.

Chronic Achilles strain may or may not be related to the 5.5% incidence of Achilles tendon ruptures reported in adult players over 40. Older racquet sports participants with poorly cushioned footwear with absent medial arch support may be prone to plantar fasciitis or rupture of the plantar fascia. Whether there is an increased risk if one played a lot when younger has never been shown. However, tennis players are particularly susceptible to this injury due to the great amount of time spent on the balls of their feet while making quick changes in direction. Hallux rigidus is a degeneration of the first metatarsophalangeal joint with dorsal exostosis, which occurs frequently in tennis players due to the excessive dorsiflexion of the first toe during play. Thus, the amount of play may be correlated to this degenerative change and thus may be increased in those who played more when younger.

Injury Risk Factors

A model has been developed to help evaluate injury and performance in sports (fig. 1) [21]. In this model, the demands inherent in participation in the sport (extrinsic factors) interact with the athlete's musculoskeletal base (the intrinsic factors) at the 'critical point' (when the ball hits the racquet) to create injury risk and performance. This model highlights the importance of the interaction between intrinsic and extrinsic factors in injury evaluation.

Extrinsic Factors

Exposure

Tennis may be considered a violent sport due to the high body segment velocities, motions, and loads inherent in the game at this skill level. Data from adult players shows that the elite player must generate 4,000 W of energy, or about 5 hp, in each serve. The entire body is involved in generating this energy. Trunk rotation velocity is around 350 deg/s, shoulder rotation velocity approaches 1,700 deg/s, and elbow extension velocity approaches 1,100 deg/s [22]. These velocities are developed rapidly over 0.4–0.6 s, creating large accelerations in the shoulder (0–43 miles/h). The total arc of shoulder internal/external

Fig. 1. The ‘critical point’ model showing the individual athlete’s musculoskeletal base interacting with the inherent demands of the sport to produce both performance and injury risk.

rotation averages 146 degrees. These velocities and accelerations produce ball velocities of 95–105 miles per hour in females and 120–135 miles per hour in males. There is no comparable data for loads in pediatric athletes, but the forces still are quite high as shown by serve velocities approaching 85 miles per hour in females and 105 miles per hour in males.

These hitting activities are combined with repetitive running and start/stop activities that involve the legs. The average point in age group tennis matches requires 8.7 changes of direction, each change creating a load of 1.5–2.7 times body weight on the planted knee [23]. These demands require patterned muscle activations to do concentric and eccentric work.

These loads are applied frequently and with high-energy demands. The elite pediatric tennis player averages 2.3 h of practice or play per day 6.1 days per week [3]. Energy expenditure evaluation reveals that the metabolic demands in tennis are 70% alactic anaerobic, 20% lactic anaerobic, and 10% aerobic [22].

Environment

Court surface may play a role in injury rates and patterns. Different court surfaces can alter the demands that are placed on the tennis player. In general, clay courts and some synthetic courts slow the ball down, allowing for longer points and longer matches, while synthetic and hard courts speed the ball up, creating more force on the arm, and keep the bounce lower. There are no specific data correlating injury to court surface.

Equipment

Several equipment factors have been associated with tennis elbow: heavier, stiffer, more tightly strung racquets, incorrect grip size, metal racquets, and racquets with increased racquet vibration [14].

Intrinsic Factors

Growth

The pediatric tennis player's growth and development create some deficits in the musculoskeletal base that may increase injury risk. Many pediatric tennis players do not have sufficient leg strength to withstand the running, starting/stopping, or power generation demands. Differential bone growth in relation to muscle length decreases muscle flexibility and strength. These alterations create varying patterns of strength and capability to improve strength during periods of rapid bone growth, and may be the most influential intrinsic risk factor. This mismatch may also lead to a decreased ability to learn efficient athletic skills, also leading to increased injury risk.

However, other intrinsic factors are due to repetitive play. They create adaptations that may be considered maladaptations in that they alter the biomechanics of the tennis strokes, creating increased injury risk.

Physical Maladaptations

Pediatric tennis players develop decreased lumbar flexibility, evaluated by sit and reach measurements, compared with age- and activity-matched controls [24]. They also show hip rotation inflexibility. These deficits have been associated with the presence of low back injury [17].

Shoulder muscle strength may also be altered. Decreased external rotation strength and muscle work lead to altered internal/external rotation ratios [25]. This combination results in force couple imbalance in the humeral head stabilizers, decreasing the concavity/compression of the humeral ball into the glenoid socket.

The most common maladaptation is alteration in shoulder internal rotation and is named glenohumeral internal rotation deficit. This appears at an early age, and progresses with age and years of play [26, 27]. Current thought recognizes Glenohumeral internal rotation deficit as a key initiator of a series of biomechanical alterations that lead to altered humeral position in arm rotation and predispose the shoulder and elbow to injury [17, 28].

These maladaptations are very common in elite pediatric tennis players with their incidence ranging from 60 to 86% of players surveyed. Their exact origin is not clear. Strength alterations may result from a plyometric-like effect that increases strength on the trunk flexors or shoulder internal rotators, actual muscle damage due to tensile stress overload, or alteration of muscle activation patterning.

The alterations in flexibility may be an internal adaptation to a repetitive tensile load. Most authors feel it is an alteration in static (the absolute magnitude of stretching) and/or dynamic (the rate at which stretching occurs, or the stiffness) flexibility in muscles. These may be present with or without alterations in strength.

Suggestions for Injury Prevention

Prevention of injuries in pediatric tennis players would center on evaluating and modifying the extrinsic and intrinsic factors that have been identified in association with injury. It appears that a reasonable model has been developed to understand the interaction of the various intrinsic and extrinsic factors, but due to the multi-dimensional, full body involvement in tennis, it is difficult to define the exact parameters to be studied. To date, no complete study has been undertaken which correlates change in risk factors with conclusive proof of injury reduction. Studies have shown that individual risk factors may be modified.

Extrinsic Factors

Many of the extrinsic factors in tennis injuries are not modifiable. All coaches and players agree that elite tennis players require a lot of practice and play to become skillful. There have been some efforts to modify the amount of tournament play. The U.S. Tennis Association decreased the number of tennis tournaments in the younger (under 12 and under 14) age groups, substituting round-robin matches. The Women's Tennis Association established tournament play restrictions for professional players under the age of 16. These restrictions did not address the amount of practice time. There are no data on the effect of these restrictions on injury incidence. Much more research on the optimum amount of time for play and practice is needed.

The inherent biomechanical and physiological demands of hitting and running can be slightly modified. There is evidence that certain aspects of the mechanics of tennis stroke production are more efficient, producing less strain on the body. Utilization of kinetic chain sequencing from the ground reaction forces creates optimum proximal force generation, interactive moments in distal segments, and produces efficient long axis rotation of the arm before ball impact. The result is a 'push-through' mechanism by which the legs drive the arm and racquet through the hitting zone, as opposed to a 'pull-through' mechanism, in which the smaller trunk and arm muscles drag the arm and racquet through the hitting zone. It has also been shown that specific alterations in mechanics, such as incomplete flexion of the knees in cocking, or incomplete cocking of the shoulder, create increased loads in the shoulder and elbow [11]. These mechanical problems should be addressed by detailed coaching analysis and training.

Intrinsic Factors

Alterations in the musculoskeletal base can be evaluated by a sport-specific preparticipation exam with special emphasis on the areas of

maximum concern. Several protocols exist [29, 30]. In order to provide meaningful data, these tests should be performed with specific guidelines. In the flexibility measurements, the proximal segments should be stabilized (pelvis for hip range of motion, scapula for glenohumeral rotation), goniometers should be used for measurement, and side-to-side comparisons are helpful for asymmetries. For strength measurement, the proximal segments (pelvis and scapula) should also be stabilized and composite motions (hip or shoulder rotation, hip abduction) should be measured because this is the way muscles are activated in tennis activities. Once again, side-to-side comparison is helpful for asymmetries.

Scapular control plays a major role in force transfer between the trunk and hand, establishing stable ball and socket kinematics and allowing maximal shoulder muscle activation. The scapula can be dynamically evaluated by observing its position at rest and motion with arm motion [31].

These prospective evaluations can then be used as the basis for a sport-specific conditioning program, using the concepts of periodization. Studies have demonstrated that changes in strength [32, 33] and flexibility [31] can be achieved. These data show a correlation between improved musculoskeletal base parameters and performance in tennis. No data exist to relate improved flexibility and strength parameters to injury in tennis players. However, there are data from other sports – running and basketball – to show this correlation.

Suggestions for Further Research

Several areas need to be addressed in order to gain more knowledge. First, a standard definition of injury must be devised and agreed upon. Second, a validated injury evaluation instrument must be implemented across all studies. Study design will need to be improved. Due to the relatively low number of injuries, the relatively wide distribution of injuries across all areas of the body, and the transient and often short term nature of high level participation in the pediatric age group. The most efficacious study of pediatric tennis injuries would be longitudinal in nature with adequate sample size to provide appropriate statistical power to evaluate intrinsic and extrinsic injury risk factors of interest. A critical aspect of this research would be the precise determination of exposure patterns in injured and uninjured athletes as a basis for determining reasons for injury occurrence. A second study would then attempt to modify all the potentially injurious factors that were identified through regression analysis from the first study through a prospective conditioning and periodized training/playing schedule, and correlate with injury incidence.

References

- 1 Kibler WB, Chandler TJ: Musculoskeletal adaptations and injuries associated with intense participation in youth sports; in Cahill B (ed): *The Effect of Intense Training on Prepubescent Athletes*. Rosemont, AAOS, 1993, pp 203–216.
- 2 Hutchinson MR, LaPrade RF, Burnett QM, Moss R, Terpstra J: Injury surveillance at the USTA boys' tennis championships: A 6-year study. *Med Sci Sports Exerc* 1995;7:826–830.
- 3 Kibler WB, McQueen C, Uhl TL: Fitness evaluations and fitness findings in competitive junior tennis players. *Clin Sports Med* 1988;7:403–416.
- 4 Lanese RR, Strauss RH, Leizman DJ, Rotonki AM: Injury and disability in matched men's and women's intercollegiate sports. *AJPH* 1990;80:1459–1462.
- 5 Safran MR, Hutchinson MR, Moss R, Albrandt J: A comparison of injuries in elite boys and girls tennis players. *Transactions of the 9th Annual Meeting of the Society of Tennis Medicine and Science*. Indian Wells, California, 1999.
- 6 Reece LA, Fricker PA, Maguire KF: Injuries to elite young tennis players at Australian institute of sport. *Aust J Sci Med Sport* 1986;18:11–15.
- 7 Winge S, Jorgensen U, Neilson L: Epidemiology of injuries in Danish championship tennis. *Int J Sports Med* 1989;10:358–367.
- 8 Silva RT, Takahashi R, Berra B, Cohen M, Matsumoto MH: Medical assistance at the Brazilian Juniors Tennis Circuit – A one-year prospective study. *J Science and Medicine in Sport* 2003;6:14–18.
- 9 Beachy G, Akau CK, Martinson M, Olderr TF: High school sports injuries. A longitudinal study at Punahou School: 1988 to 1996. *Am J Sports Med* 1997;25:675–681.
- 10 Ireland ML, Hutchinson MR: Upper extremity injuries in young athlete. *Clin Sports Med* 1995;14:533–571.
- 11 Elliott BC, Fleisig G, Nicholl R, et al: Technique effects on upper limb loading in the tennis serve. *J Sci Med Sport* 2003;6:76–87.
- 12 Lehman RC: Shoulder pain in the competitive tennis player. *Clin Sports Med* 1988;7:309–327.
- 13 Paterson PD, Waters PM: Shoulder injuries in the childhood athlete. *Clin Sports Med* 2000;19:681–692.
- 14 Nirschl RP: The etiology and treatment of tennis elbow. *Am J Sports Med* 1974;2:308–323.
- 15 Hellstrom M, Jacobsson B, Sward L, Peterson L: Radiologic abnormalities of the thoracolumbar spine in athletes. *Acta Radiol* 1990;31:127–132.
- 16 Sward L, Hellstrom M, Jacobsson B, Peterson L: Anthropometric characteristics, passive hip flexion, and spinal mobility in relation to back pain in athletes. *Spine* 1980;15:376–382.
- 17 Vad VB, Gebel A, Dines D, et al: Hip and shoulder internal range of motion deficits in professional tennis players. *J Sci Med Sport* 2003;6:71–75.
- 18 Renstrom PAFH: Knee pain in tennis players. *Clin Sports Med* 1995;14:163–175.
- 19 Lobst CA, Stanitski CL: Acute knee injuries in pediatric athletes. *Clin Sports Med* 2000;19:621–636.
- 20 Bruns W, Maffuli N: Lower limb injuries in children in sports. *Clin Sports Med* 2000;19:637–662.
- 21 Kibler WB, Chandler TJ: Preparticipation evaluations; in Renstrom P (ed): *Sports Injuries: Basic Principles of Prevention and Care*. Oxford, Blackwell, 1993, pp 223–241.
- 22 Kibler WB: Evaluation of sports demands as a diagnostic tool in shoulder disorders; in Matsen FA, Fu FH, Hawkins RT (eds): *The Shoulder: A Balance of Mobility and Stability*. Rosemont, AAOS, 1993, pp 379–399.
- 23 Kibler WB, Safran MR: Musculoskeletal injuries in the young tennis player. *Clin Sports Med* 2000;9:781–792.
- 24 Chandler TJ, Kibler WB, Uhl TL, et al: Flexibility comparison of junior elite tennis players to other athletes. *Am J Sports Med* 1990;18:134–136.
- 25 Chandler TJ, Kibler WB, Stracener EC: Shoulder strength, power, and endurance in college tennis players. *Am J Sports Med* 1992;20:455–458.
- 26 Kibler WB, Chandler TJ, Livingston BP, et al: Shoulder range of motion in elite tennis players. *Am J Sports Med* 1996;24:279–285.
- 27 Roetert EP, Ellenbecker TS, Brown SW: Shoulder internal and external rotation range of motion in junior tennis players: A longitudinal analysis. *J Strength Cond Res* 2000;14:140–143.

- 28 Burkhardt SS, Morgan CD, Kibler WB: Current concepts: The disabled throwing shoulder: Spectrum of pathology part I. *Arthroscopy* 2003;19:404–420.
- 29 Kibler WB, Chandler TJ: Range of motion in junior tennis players participating in an injury risk modification program. *J Sci Med Sport* 2003;6:51–62.
- 30 U.S. Tennis Association High Performance Profile, Key Biscayne, FL.
- 31 Kibler WB, McMullen J: Scapular dyskinesis and its relation to shoulder pain. *J Am Acad Orthop Surg* 2003;11:142–152.
- 32 Cohen BD, Mont MA, Campbell KR, et al: Upper extremity physical factors affecting tennis serve velocity. *Am J Sports Med* 1992;22:746–754.
- 33 Trieber FA, Lott J, Duncan J, et al: Effects of Thera-Band and dumbbell training on shoulder rotation torque and serve performance in college tennis players. *Am J Sports Med* 1998;26:510–513.

W. Ben Kibler, MD
Medical Director
Lexington Sports Medicine Center
1221 South Broadway, Lexington, KY 40504 (USA)
Tel. +1 859 258 85 75, Fax +1 859 258 85 62, E-Mail WKibler@aol.com