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REVIEW

Tennis injuries: occurrence, aetiology, and prevention

B M Pluim, J B Staal, G E Windler, N Jayanthi

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A systematic search of published reports was carried out in three electronic databases from 1966 on to identify relevant articles relating to tennis injuries. There were 39 case reports, 49 laboratory studies, 28 descriptive epidemiological studies, and three analytical epidemiological studies. The principal findings of the review were: first, there is a great variation in the reported incidence of tennis injuries; second, most injuries occur in the lower extremities, followed by the upper extremities and then the trunk; third, there have been very few longitudinal cohort studies that investigated the association between risk factors and the occurrence of tennis injuries (odds ratios, risk ratios, hazard ratios); and fourth, there were no randomised controlled trials investigating injury prevention measures in tennis. More methodologically sound studies are needed for a better understanding of risk factors, in order to design useful strategies to prevent tennis injuries.

the duration and nature of treatment, time lost from sports participation or work, permanent disability, and cost.⁹ Another important step is to determine risk factors and other mechanisms that are associated with these injuries.^{9,10} This aetiological research entails understanding the causes of injury, with the goal that modification or removal of these causes can prevent the occurrence of the injuries.¹⁰ The next step consists of the formulation of preventive measures.¹⁰ These measures must be evaluated with regard to their effectiveness before implementation. Ideally, evaluation should include randomised controlled trials.^{10–12}

Our aim in this review of published reports was to provide an overview of the available scientific knowledge on the occurrence, aetiology, and possibilities for prevention of tennis injuries. We asked the following three questions. First, what are the most common tennis injuries, based upon the reported prevalence and incidence figures? Second, what associated risk factors and mechanisms are described with regard to the aetiology of tennis injuries? And third, what is known about the efficacy of prevention efforts designed to reduce the occurrence of tennis injuries?

Another purpose of this review was to identify gaps in knowledge with respect to the occurrence, aetiology, and prevention of tennis injuries and to encourage further methodologically sound epidemiological research in this field.

METHODS

We undertook a literature search to retrieve potentially relevant articles published since 1966. The following electronic databases were explored: Pubmed (from 1966 to October 2005), Embase (from 1989 to October 2005), and Cumulative Index to Nursing and Allied Health Literature (CINAHL) (from 1982 to October 2005). A priori defined search terms (Medical subject heading (Mesh) and text words) that were used in this search were: “injury”, “injuries”, “prevalence”, “incidence”, “incidence density”, “proportion”, “distribution”, “population”, “aetiology”, “etiology”, “mechanism”, “risk factor”, “risk factors”, “prevention” and “intervention”. These terms were combined with “tennis”. Reading titles and abstracts identified potentially relevant articles. Citation tracking of the articles retrieved was also performed to identify additional relevant articles.

To be included in this review studies had to meet the following inclusion criteria: they must contain data on tennis injuries; they must investigate the frequency of tennis injuries, the aetiology (for example, risk factors) of tennis injuries, the efficacy of prevention strategies, or a

Tennis is a global sport, with participation in more than 200 countries affiliated with the International Tennis Federation.¹ It is also a professional sport in which millions of dollars in prize money are at stake for both men and women players. In the Netherlands, it is the second most popular sport, with more than one million participants from a population of 16 million.² Among Dutch women it is actually the most popular sport.³ In other European countries tennis also ranks high on the list of popular sports.³

Like many other sports, playing tennis—at either a recreational, collegiate, or professional level—places participants at risk of injury. Though many injuries that occur in tennis are common to other sports, tennis does have a unique profile of injuries.⁴ Differences in equipment, biomechanics, and physical demands result in an injury profile that differs from other racquets and throwing sports.⁴ Sports injuries, including tennis injuries, are a common cause of disability and, in some cases, absence from work.^{5–7} This can have substantial socioeconomic consequences, both on a personal and a societal level.⁸ For these reasons it is important to develop effective measures for the prevention of tennis injuries.

To develop prevention strategies, both the incidence and severity of tennis injuries must be determined. The severity of an injury can be described on the basis of the nature of the injury,

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combination of these purposes; and they must have been published in English, German, or Dutch. Studies focusing on treatment for tennis injuries and literature reviews were excluded. For the purpose of this review we defined a tennis injury as a musculoskeletal problem requiring reduction or interruption of tennis activity for any length of time, with or without evaluation or treatment by a health care provider.¹³

We did not expect to find many cohort or randomised controlled studies in this field. Furthermore, with the expected heterogeneity in study designs and methods, we elected not to follow a formal meta-analytic approach. The studies retrieved were classified as case reports, laboratory studies, descriptive epidemiological studies, analytic epidemiological studies, or intervention/prevention trials. A similar approach was conducted earlier by Pollack *et al*^{14 15} with regard to the available evidence for the prevention of softball injuries. For reasons of clarity we defined descriptive epidemiological studies a priori as cohort studies (either cross sectional or longitudinal), describing the frequency (that is, prevalence or incidence or both) of tennis injuries in a cohort or subcohort. Analytic epidemiological studies were defined as cohort studies (either cross sectional or longitudinal) which aimed to estimate a measure of association (that is, odds ratio, risk ratio, hazard ratio) between risk factors and the occurrence of tennis injuries. The results of the selected studies will be described and summarised to formulate answers to the research questions posed above. The emphasis lies on the results of descriptive and analytic epidemiological studies, and intervention/prevention studies rather than laboratory studies or case series and reports.

RESULTS

Our search in the Pubmed, Embase, and Cinahl databases resulted in, respectively, 1368, 1617, and 2460 potentially relevant hits. To identify appropriate papers for the present review, the titles and abstracts were read and, if considered relevant, selected by two persons (BMP and JBS). In cases of disagreement further discussion was undertaken to achieve consensus. We found 39 case reports, 49 laboratory studies, 28 descriptive epidemiological studies, three analytic epidemiological studies, and no intervention study which met the inclusion criteria of the present review. Table 1 provides an overview of the distribution of study type and body region within the relevant articles.

Case reports

Of the 39 case reports, 29 dealt with injuries of the upper extremity,¹⁶⁻⁴⁴ eight with injuries of the lower extremity,⁴⁵⁻⁵² and two with the trunk.^{53 54} Of the case reports, the most common condition in the upper extremity injury section was stress fractures (14 case reports).¹⁶⁻²⁹ Stress fractures in the upper extremity included the metacarpals, hamate bone, radius, ulna, and humerus. The suggested causal mechanism involved repeated loading on the upper extremity during the tennis stroke,^{27 28} and included the impact of the racket butt against the palm of the hand,¹⁶⁻¹⁸ and high torsional stresses.^{25 27 28}

Vascular injury in the upper extremity was mentioned four times.³²⁻³⁵ Though an uncommon injury, it has also been reported in overhead batting and racquet sports. Vascular injury may result from compression of the large vessels in the axilla during the service motion, resulting in aneurysm formation.³⁵ Distal embolisation may occur.³⁴ Endothelial injury caused by repeated microtrauma to the hand by the racket was also reported.^{32 33}

Regarding the lower extremity, injuries were more equally distributed and included case reports on tendon injuries,^{46 48} plantar fascia tears,^{49 52} muscles tears,⁴⁵ stress fractures,^{47 50} and intra-articular knee injury.⁵¹

Laboratory studies

Forty nine laboratory studies were identified: 36 involved the upper extremity,⁵⁵⁻⁹⁰ six the lower extremity,⁹¹⁻⁹⁶ three the trunk,⁹⁷⁻⁹⁹ and four the whole body.¹⁰⁰⁻¹⁰³ In the upper extremity articles, the following topics were discussed most often: range of motion (seven studies)^{55 58 61-65} and strength (nine studies)^{55-60 62 65 66} of the shoulder, and biomechanical analysis of the stroke (six studies).^{69-71 74 75 77}

In the studies examining range of motion of the shoulder, internal and external rotation was measured using a goniometer. In six^{58 61-65} of seven studies^{55 58 61-65}, a significant decrease of internal rotation and total range of motion was demonstrated in the dominant arm. Kibler *et al*⁶⁴ showed that the loss of total range of motion was progressive with age and years of tournament play.

Muscular strength of the shoulder was determined by isokinetic testing. Five^{58-60 62 65} of seven studies^{55 56 58-60 62 65} showed an imbalance of muscle strength, with significantly greater isokinetic strength in the dominant arm than in the non-dominant arm for internal rotation, leading to a reduced external/internal rotation ratio. Both the loss of internal rotation motion and the muscle strength imbalance were hypothesised to increase the risk of shoulder injuries.

In three^{91 95 96} of the six articles⁹¹⁻⁹⁶ focusing on the lower extremity, the interaction between shoe and court surface was examined. The main conclusion of these studies was that lateral stability of the shoe is important in the prevention of injuries.

Descriptive epidemiological studies

Twenty eight descriptive epidemiological studies were identified, including 19 on tennis injuries in general,¹⁰⁴⁻¹²⁴ seven on injuries of the upper extremity,¹²⁵⁻¹³² one on the lower extremity,¹³³ and one on the trunk.¹³⁴

Injury incidence

Injury incidence varied from 0.05¹²²⁻¹²⁴ to 2.9¹¹⁹ injuries per player per year (table 2). Per hour of play, the reported incidence varied from 0.04 injuries/1000 hours¹⁰⁸ to 3.0 injuries/1000 hours.¹⁰⁵ Incidence and prevalence rates for tennis elbow were quite high, with reported incidence varying from 9%¹²⁸ to 35%¹³⁰ and prevalence varying from 14%¹²⁸ to 41%.^{131 132}

Table 1 Distribution of identified studies by type of study and body region

	Case studies	Laboratory	Descriptive epidemiological	Analytical epidemiological	Intervention and prevention
General	0	4	19	1	0
Upper extremity	29	36	7	0	0
Lower extremity	8	6	1	1	0
Trunk	2	3	1	1	0
Total	39	49	28	3	0

Table 2 Characteristics and results of included descriptive epidemiological studies

Study*	Study design	Study population	Injury definition	General incidence	Upper ext (%)	Lower ext (%)	Trunk/head (%)	Type of injury reported	Severity
Vriend ¹⁰⁴	Cross sectional study: telephone interviews, with recall period of 3 m (2000–2004)	General population: in each of the 5 y, 10 000 people were interviewed, of whom ~50% were sports participants	All acute and chronic injuries or ailments that developed as a result of or during sports participation in the past 3 m	1.1/1000 h: O/D 0.9/1000 h: I/D 1.6/1000 h	29.1	53.6	10.2 (not defined 3.7)	NR	52% required medical treatment (O/D 49%, I/D 59%, NS)
Joyanhi ¹⁰⁵	Cross sectional, questionnaire; recall period 1 y	140 M, 388 F recreational league players (International Tennis Number 3 to 8); mean age 46.9 y	Any injury or pain the player had experienced in the past 12 m preventing play for ≥7 d	3.0 inj/1000 h; prevalence 52.9 inj/1000 players	41	49	3	Overuse injuries predominated, most in upper extremity	NR
Kühne ¹⁰⁶	Prospective study, follow up 6 months	60 competitive, 50 recreational players; C range 16–35 y, mean 25; R range 40–68 y, mean 53	The injuries and problems that the player experienced during the tennis season	1.5 inj/player/y	25	64	11	Cramps, strains, and sprains were most common	3.3% of acute and 2.2% of chronic injuries were eventually operated
Da Silva ¹⁰⁷	Prospective study with 1 y follow up; all medical treatments required during tournament	Elite junior players, participating in the national circuit in Brazil in the <12, <14, <16, and <18 age categories	Any consultation and/or treatment given to a player during a tournament on site	6.9 medical treatment/1000 games played	NR	NR	NR	Cramps (muscle contorture) were most common	NR
LIS 1999–2003 ¹⁰⁸	Prospective study of injuries treated at the first aid department of 15 selected hospitals in Netherlands	General population; 7700 tennis players	Injuries requiring treatment at the first aid department of the hospital	0.04 inj/1000 h	28	59	13	Acute, more severe type of injuries; sprains most common (59%)	Costs per injury €830; 5% hospitalised for an average of 5 d
Schmikli ¹⁰⁹	Cross sectional study: telephone interviews; recall periods 1 month (1986–87), 1 month (1992–93), and 3 months (1997–98)	General population, 1982–83; 67 139 persons, of whom 31 688 played sports	Injuries or ailments newly developed as a result of or during sports participation in the past 4 wk (3 mj); chronic injuries not recorded	1986–87: I/D 1.8/1000 h; O/D 1.2/1000 h; 1992–93: I/D 2.9/1000 h; 1997–98: I/D 1.0/1000 h; O/D 0.5/1000 h	NR	NR	NR	NR	Medical treatment required: O/D, 27%, 34%, and 39% of injuries; I/D, 57%, 60%, and 66%
Sallis ¹¹⁰	Retrospective cohort study of injury reports compiled by athletic trainers with a 15 y follow up period	College players; range 18–22 y; 3767 participants, divided over sports, including tennis	Medical problem as a result of sport participation requiring visit to training room	0.456 M, 0.425 F per player/y	23.1 M; 21.9 F	62.2 M; 70.7 F	14.6 M; 7.2 F	NR	No ACL injuries, otherwise NR
Steinbrück ¹¹¹	Prospective longitudinal study with 25 y follow up; visits to sports orthopaedic and trauma OPD	General population; 1257 M and 858 F tennis players	Not defined: any medical problem that required a visit to the sports medicine clinic was registered as an injury	NR	21	60	19	Knee 25%; ankle 23%	NR
Weijermans ¹¹²	Prospective cohort study of 46 tennis clubs; follow up 6 months (O/D tennis season); injuries reported to contact person	179 club players	Tennis related problem resulting in loss of practice or match time, need for medical consultation, or negative social/economic consequences (absence from school/work)	0.11/1000 h	NR	67	NR	Mostly acute injuries; tennis leg and sprained ankle most common	For the 5 most common injuries, 60% needed medical consultation, and 20% absence from school/work

Table 2 (Continued)

Study*	Study design	Study population	Injury definition	General incidence	Upper ext (%)	Lower ext (%)	Trunk/head (%)	Type of injury reported	Severity
Hutchinson ¹¹³	Prospective cohort study, with follow up of 6 y	1440 male participants at the USA National Boys Championships 1986–1988; 1990–1992	Any medical problem requiring physical or medical assistance	21.5/1000 athletic exposures; 9.9/100 players	26	51	22	Sprains 58%	One athlete transported to hospital for heat exhaustion
Baxter-Jones ¹¹⁴	Prospective cohort study	156 elite players in five 2-y age groups from 8–16 y	Any injury resulting in discontinuation of training and/or medical treatment	0.52 inj/player/y	NR	NR	NR	Osteochondrosis 26%	Acute injuries 13 d lay-off time; chronic injuries 20 d
Lanese ¹¹⁵	Prospective cohort study	12 M, 11 F college players, 18–22 y	Traumatic medical problem due to sports participation resulting in time loss from practice or competition	1.6 inj/1000 h (M); 1.0 inj/1000 h (F), p=0.37	NR	NR	NR	NR	2.42 (0.57) disability d per 100 person h
Winge ¹¹⁶	Prospective study, follow up 6 months (O/D tennis season)	Elite players: 61 M, mean age 28 y; 28 F, mean age 22 y	Every problem that appeared in connection with tennis, handicapped the player during play, and/or required special treatment	0.52 inj/player/season; 2.3 inj/1000 h (M 2.7, F 1.1)	45.7	39	11	Shoulder injuries 17%	Mean injury period 44.5 d; absence from work practically 0
Krause ¹¹⁷	Gross sectional	78 M + 49 elite players, age range 15–46 y	NR	0.7 inj/player/y	36.4	44.3	19.3	Shoulder, back, and ankle 85%	NR
Chard ¹¹⁸	Longitudinal study, 8 y follow up; visits to sports medicine clinic	78 M + 53 recreational players, age range 8–66 y	Medical problem related to tennis that required a visit to the sports injury clinic (self referral for acute injuries; referral by GP for chronic injuries)	NR	35	45	20	PF problems 44%; acute injuries 70%; chronic injuries 30%	NR
Reece ¹¹⁹	Retrospective cohort study: injuries requiring attention of medical officer or physiotherapist	24 M + 21 F elite players at Australian Institute of Sport, aged 16–20 y, mean 17.6	Any injury that required attention from the medical officer or physiotherapist	2.5 inj/player/y (M); 2.9 inj/player/y (F)	20	59	21	Ankle sprain most common, followed by calf and quadriceps strain	2 conditions required surgical intervention
Von Salis-Soglio ¹²⁰	Gross sectional study: interview and medical examination	15 elite M players, 1–15 in German National ranking; mean age 28 y; range 15–43	NR	NR	NR	NR	NR	Shoulder and elbow problems (tennis elbow) most common	Small risk for long term problems
Von Krämer ¹²¹	Retrospective study, follow up 17.5 y	100 M and 26 F recreational players, mean age 43 y	Complaints and diseases which resulted from playing tennis	NR	47.5	31.1	16.6	Tennis elbow 39%; Achilles tendon 15%	NR
Biener ¹²²⁻¹²⁴	Gross sectional	203 M, 72 F high level competitive players; mean age 28 y	NR	0.05 inj/player/y	48.6	43.4%	2/6	Tennis elbow 36%; sprains 21%; strains 14%	NR

*First author and reference number.

ACL, anterior cruciate ligament; ; d, days; ext, extremity; F, female; I/D, indoor; inj, injury; h, hours; m, months; M, male; NR, not reported; O/D, outdoor; OPD, outpatient department; PF, patellofemoral joint; wk, weeks; y, years.

Table 3 Characteristics and results of included analytic epidemiological studies

Study*	Study design	Study population	Risk factors	Outcomes	Adjustment for confounders	Results
Llana ¹³⁷	Cross sectional study	A sample of 146 tennis players in Spain selected from a sample of 4000 who had completed a questionnaire on "discomfort" associated with tennis shoes	Perceived design errors	Discomfort	No	Significant correlation ($p=0.02$) between incorrect arch support and plantar discomfort
Spector ¹³⁵	Retrospective cohort study	81 female ex-elite athletes (67 middle and long distance runners, and 14 tennis players), aged 40–65, recruited from original playing records, and 977 age matched female controls from London UK	Long term weight bearing sports activity	Pain OA as defined by radiological changes (joint space narrowing and osteophytes) in hip joints, PF joints, and TF joints	Yes	The ex-athletes had greater rates of radiological OA at all sites. This association was strongest for the presence of osteophytes at the TF joints (OR=3.57 (95% CI, 1.89 to 6.71)), at the PF joints (OR=3.50 (1.80 to 6.81)), narrowing at the PF joints (OR=2.97 (1.15 to 7.67)), femoral osteophytes (OR=2.52 (1.01 to 6.26)), and hip joint narrowing (OR=1.60 (0.73 to 3.48)), and was weakest for narrowing at the TF joints (OR=1.17 (0.71 to 1.94)). The tennis players tended to have more osteophytes at the TF joints and hip
Nigg ¹³⁶	Prospective cohort study (2 m follow up)	171 members of tennis clubs	Shoe, temperature, type and duration of match play, subjective assessment of shoe comfort, sole grip and lateral stability	Pain	No	Stiffness of shoe and subjective evaluation of frictional properties of the shoe were significantly associated with pain

Only statistically significant results are reported.

*First author and reference number.

CI, confidence interval; m, months; OA, osteoarthritis; OR, odds ratio; PF, patellofemoral; TF, tibiofemoral.

Injury localisation

Ten^{104–106 108 110–113 117 119} of 13 studies^{104–106 108 110–113 116 117 119 121–124} showed a preponderance of injuries of the lower extremity compared with the upper extremity.

Injury type

Four^{108 112 113 118} of six studies^{105 108 112 113 116 118} reported more acute than chronic injuries. Most acute injuries occurred in the lower extremities, whereas most chronic injuries were located in the upper extremities. Injuries to the trunk comprised 5% to 25% of all injuries.^{104–106 108 110 111 113 116–119 121–124}

Injury severity

Injury severity was expressed in various ways in the different studies, including number of injuries requiring hospital admission^{108 113} or operative treatment,¹⁰⁶ average medical costs per injury,¹⁰⁸ time loss,^{114 115} or the percentage requiring medical treatment.^{104 109 112} Injuries sustained while playing indoors tended to be more severe than outdoor injuries, with a higher percentage requiring medical treatment.^{104 109} In the study by Kuhne *et al*, 3.3% of acute and 2.2% of chronic injuries required surgery.¹⁰⁶ Five per cent of the injuries in the Letsel Informatie Systeem (LIS) study required an average of five days of hospital admission.¹⁰⁸ In the studies on juniors, injury severity was significantly less, with only one player of 1440 being taken to hospital and two injuries of 176 requiring surgery.¹¹³

Sex

Injury rates between men and women were compared in a prospective cohort study of intercollegiate tennis.¹¹⁵ In this study, 1.6 injuries per 1000 hours were recorded for male tennis players versus 1.0 injury per 1000 hours in female

players. This was not a statistically significant difference ($p=0.37$).

Sallis *et al*¹¹⁰ studied injury patterns in 18–22 year old tennis players. This was a retrospective cohort study of injury reports compiled by certified athletic trainers. The incidence was 0.46 injuries per male player per year and 0.42 injuries per female player per year. The differences were not statistically significant.

Hutchinson *et al*¹¹³ compared injury patterns in elite junior players (male and female) during a three year period (1996–1998) at the United States Tennis Association (USTA) tennis championships. There was no significant difference in the overall rate of injury (new and recurrent) between male and female players.

Winge *et al*¹¹⁶ found a higher injury rate in men (2.7 injuries per 1000 hours) than in women (1.1 injuries per 1000 hours). This was a statistically significant difference ($p<0.05$).

Age

The Letsel Informatie Systeem¹⁰⁸ is a continuous registration of injuries treated in the emergency departments of a selection of 15 hospitals and medical centres in the Netherlands. These injuries are generally acute and more serious. In this study, injury risk in tennis has been shown to gradually increase with age, from 0.01 injuries per player per year in the 6–12 year age group to 0.5 injuries per player per year in those over 75 years of age. An increased incidence with age was consistently shown for tennis elbow.^{127–132}

Level of play

In these general descriptive epidemiological studies, the study populations can be characterised as recreational/

general, elite, or junior competitive. The studies include a wide distribution of retrospective, cross sectional, prospective cohort, and prospective longitudinal study designs. There were nine studies^{104–106 108 109 111 112 118 121} involving recreational players or the general population, seven studies^{110 115–117 119 120 122–124} involving elite players, and three studies^{107 113 114} relating to junior tournament players. Study designs of junior and elite players often involved recording of injuries as medical consultations at tournaments or training centres. This method of injury reporting may inflate injury rates, therefore making it difficult to make direct comparisons with studies involving recreational players that often involve self reporting of their injuries.

We were able to identify only two studies that compared injury rates between players of different ability. Baxter-Jones *et al*¹¹⁴ studied elite young athletes. They found that performance success was significantly related to injury rate. Jayanthi *et al*¹⁰⁵ described the incidence and prevalence of injuries in recreational players of different skill levels, ranging from International Tennis Number 3 to 8. Despite trends, there were no statistical differences in overall injury incidence and prevalence rates across all skill levels.

Volume of play

Studies describing the risks associated with volume of play are scarce. Increased playing time was associated with increased incidence of new cases of tennis elbow in recreational players playing more than two hours a day versus those playing less than two hours a day.¹²⁸ However, total incidence and prevalence of all tennis related injuries was not different among recreational players who played less than four hours a week, four to six hours a week, or more than six hours a week.¹⁰⁵

Analytic epidemiological, and intervention studies

Three studies were found that investigated risk factors for tennis injuries (table 3). Two of these^{135 136} had a longitudinal study design and one¹³⁷ was cross sectional. Adjustments for confounding variables was made in one longitudinal cohort study.¹³⁵ The type of sports injury described in the investigated studies was variable and consisted of discomfort or pain from wearing tennis shoes, sport related injuries in general, low back pain, and osteoarthritis.

Llana *et al*¹³⁷ described in a cross sectional study a significant correlation ($p = 0.02$) between perceived incorrect arch support and plantar discomfort. Spector *et al*¹³⁵ found that long term weight bearing sports activity was associated with the development of osteoarthritis.

No intervention study was retrieved investigating the effects of prevention measures on tennis injuries.

DISCUSSION

The principal findings of our study are first, that there is a great variation in the reported incidence rate of tennis injuries; second, that most injuries occur in the lower extremities, followed by the upper extremities and then the trunk; third, that there are very few cohort studies available that estimate a measure of association between risk factors and occurrence of tennis injuries; and fourth, that there are no randomised controlled trials on preventative measures in tennis.

The variation in the reported incidence rates of tennis injuries most probably reflects variation in injury definition, study design, populations under study, methods of data collection, and the duration of follow up or recall period. The lowest incidence rate (0.04 injuries per 1000 players per year) was reported in the LIS study.¹⁰⁸ Injuries in this study included only those for which the player was treated at a hospital casualty department. This implies that predominantly

more acute and serious injuries will be reported, as players with less serious and chronic injuries are more likely to visit their general practitioner, physiotherapist, or sports physician. The other study with a relatively low injury rate (0.11/1000 hours of play) was by Weijermans *et al*.¹¹² In that study, injuries sustained by tennis players at a club had to be reported to a contact person in order to be recorded. This may have resulted in under-reporting of injuries. Biener *et al*^{122–124} also reported a very low injury rate, which can be explained by their long recall period of 17.5 years.

The highest injury rates were found by Hutchinson *et al*¹¹³ and Silva *et al*.¹⁰⁷ This is undoubtedly related to their rather inclusive injury definitions: “any medical problem that required physical or medical assistance”¹¹³ and “any consultation and/or treatment given to a player during a tournament on site”,¹⁰⁷ respectively. Using these definitions, injuries which may not have had any effect on tennis play, time loss, or work were also included. Kuhne *et al* addressed this problem by making a separate category for “Bagatellverletzungen” (minor injuries), which included sunburns, abrasions, and blisters. We were not able to find any study that identified the relation of match volume within a tournament or through a season and the risk of injury. Prospective studies of independent risks associated with increased playing time in junior tournament players are lacking and necessary in order to counsel parents, coaches, and tournament directors with appropriate evidence based recommendations.

Despite the wide variation of reported injury rates and study designs, comparisons of injury rates in tennis can be made with the rates in other sports. In order to make optimal comparisons, similar study designs and injury definitions should be used. There were 377 injuries in 456 matches involving all team sports studied during the 2004 summer Olympic Games.¹³⁸ There was a total injury incidence of 0.8 injuries per match and 54 injuries per 1000 player matches, where injury was defined as any physical complaint incurred during the match that received medical attention regardless of consequence. Handball players (114/1000 player matches) and soccer players (108/1000 player matches) had the highest injury rates, while volleyball players (7.7/1000 player matches) had the lowest. With a similar definition of injury and comparable study design, Hutchinson *et al*¹¹³ reported 21.5 injuries/1000 athletic exposures and Silva *et al*¹⁰⁷ reported 6.9 medical appointments/1000 games in prospective studies of junior national tournament tennis players.

It may be more appropriate to compare tennis with other individual non-contact sports rather than contact team sports. A retrospective cohort survey study in golfers reported 3.06 injuries/player injured in professional players of average age 36.5 years, and 2.07 injuries/player injured in amateur players of average age 47.2 years.¹³⁹ This study did not report the total prevalence of injuries/100 players but had a total of 637 injuries in 703 golfers surveyed. In a cross sectional survey of recreational tennis players with an average age of 46.9 years, there were 299 injuries in 528 players giving a prevalence of 52.9 injuries/100 players.¹⁰⁵ In a cross sectional survey study of recreational runners, 45.8% of 4358 male joggers sustained jogging injuries in the previous one year period.¹⁴⁰ A prospective study of recreational runners training for a 10 km race reported that 29.5% of runners experienced an injury that caused at least some pain after exercise.¹⁴¹ Comparable prospective studies of recreational tennis players over a six month period reported injury rates of 0.11/1000 hours played¹¹² and 1.5 injuries/player/year.¹⁰⁶

Despite some variation in study design and definition of injury, tennis appears to have lower injury rates than contact team sports and also in some comparisons with non-contact individual sports such as golf and running. However, no

known study has made direct comparisons between risks of injury or lifetime prevalence of injury between tennis and other sports.

Unfortunately, we were not able to identify any intervention studies on tennis injuries. An intervention study by Kibler *et al.*,¹⁴² in which 51 tennis players undertook a specific programme of stretching exercises showed that the exercises improved the range of motion. Although they did not record the rate of injury, the authors hypothesised that this stretching programme would reduce injury risk. There is currently no evidence that limited flexibility is associated with an increased risk for tennis injuries. In a systematic review of intervention studies on the effect of stretching, Herbert and Gabriel¹⁴³ showed that stretching before exercise did not result in a reduction of injury risk. However, they noted that generalisation of this conclusion required further testing. It therefore may be worthwhile to investigate the effects of the type of programme designed by Kibler *et al.*¹⁴² on the occurrence of tennis injuries.

The aim of the present literature review was to provide an overview of available knowledge on the occurrence, aetiology, and prevention of tennis injuries. For practical reasons we refrained from doing a formal methodological quality assessment of individual studies or a quantitative data synthesis. However, by presenting studies with different study designs, a picture emerges that represents the current base of knowledge in this field. It is clear from the results that further studies on injury rates, risk factors, and prevention of tennis injuries are needed. Researchers should, if possible, choose a prospective study design in order to decrease the risk of recall bias.

A comparison of injury rates across studies will be facilitated when similar definitions of injuries are used and are clearly stated in the studies. The injury definitions in the studies in this review can be categorised as “time loss”, “medical assistance”, and “tissue injury” definitions.^{144 145} Each definition has advantages and disadvantages¹⁴⁵ and delivers its own scope at the problem of tennis injuries. A clear benefit of using a “time loss” definition is that it will generally result in the recording of injuries which substantially affect the player’s health or performance, or both.¹⁴⁵

Few studies have been carried out on the reliability of injury recording systems, and this should therefore also be priority for future research.¹⁴⁵⁻¹⁴⁷ To improve the reliability of data collection it would be wise to use instruction manuals for observers. Another important epidemiological variable is exposure time. This is a measure of participation time in training and matches. It represents the amount of time the player is at risk of injury. The exposure time should, if possible, be recorded individually for each player. Individually recorded exposure times enable researchers to study risk factors in an advanced way by using a Cox proportional hazards regression model.¹⁴⁸ However, because of practical limitations in many cases—especially in large cohort studies—estimates of exposure time must be used.

Currently, based on this literature review, we were unable to identify measures proven to prevent tennis injuries. There are no randomised controlled trials available, and the limited results of the studies on risk factors for tennis injuries fail to provide a clear perspective. Clinical experience and also the results of prevention studies in other sports^{114 115} suggest that physical training specifically targeting injury-prone movement patterns may lead to beneficial results. It would be very interesting to test the hypothesis put forward by Kibler associating loss of glenohumeral internal rotation (GIRD) and shoulder strength imbalance with an increased risk of shoulder injuries.¹⁴²

Other possibilities for prevention include: education of players, parents, and coaches about tennis injuries, interval

What is already known on this topic

There is a great variation in the reported incidence rate of tennis injuries. Most injuries occur in the lower extremities, followed by the upper extremities and the trunk. Most acute injuries occur in the lower extremities, whereas most chronic injuries are located in the upper extremities.

What this study adds

By presenting studies with different study designs, a picture emerges that represents the current base of knowledge in this field. It is clear from the results that further studies on injury rates, risk factors, and prevention of tennis injuries are needed. A possible standard protocol for future studies is presented.

musculoskeletal screening of players to identify problem areas before injuries occur, and adjustment of equipment including shoes, racquets, strings, and balls as well as court surfaces. However, further research is needed to move from a stage of clinical expertise and speculation to real evidence based prevention of tennis injuries.

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