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LOBBING INJURY OUT OF TENNIS:

A REVIEW OF THE LITERATURE

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Abstract:

Over 362,000 Australians over the age of 15 years participate in tennis. It is the third most popular sport and physical activity in Australia behind aerobics and golf. Participation provides physical fitness either in a highly competitive or social atmosphere. The public exposure that professional tennis receives and the vast amount of money involved impact upon young tennis players. This leads to great pressure to practice, high expectations of performance and increasing demands on the human body. Tennis requires a variety of physical attributes (speed, power, endurance, strength and balance) and specific playing skills. Therefore, participants should train and prepare to meet at least a minimum set of physical, physiological and psychological requirements to cope with the demands of play and reduce the risk of injury.

Emergency department presentation data collected by the Victorian Injury Surveillance System (VISS) indicate that 69% of adult tennis injury cases and 40% of child injury cases occurred during formal competition. Injuries to adults in formal play were predominantly to the lower limb (55%), particularly sprains and strains to the ankle (15% of all injuries) and knee (12%). Overexertion was the most common cause of adult tennis injury during formal play. Forty-five percent of all child tennis injuries in formal play were to the upper extremities, particularly fractures of the radius/ulna (7% of all injuries) and sprain/strains of the wrist (4%). Most child injuries in formal play were caused by falls.

The overall aim of this report is to critically review both the formal research literature and informal sources that describe measures to prevent tennis injury together with an assessment of the extent to which they have been formally demonstrated to be effective. Countermeasures to injury include pre-season conditioning, warm-up programs, attention to environmental conditions, prevention and management of overuse injuries, appropriate footwear, modified rules, education and coaching, first aid and rehabilitation. Recommendations in this report include: extension of pre-participation evaluation; the further development of equipment innovations that protect against injury; improvements to education and training for players and coaches, particularly at the wider community level; promotion of modified games for children; provision of appropriate and prompt first aid by trained personnel; improvements to injury data collections; and further epidemiological, biomechanical and laboratory research into the causes of tennis injuries and measures to prevent them.

Key Words:
(IRRD except when marked*)
Tennis, injury prevention, overuse, evaluation, countermeasures

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EXECUTIVE SUMMARY

Tennis is one of the most popular sports in the world. Every day it is played by millions of people of all ages at various standards. Participation in tennis provides physical fitness either in a highly competitive or social atmosphere. The public exposure of professional tennis and the vast amount of money involved has impacted upon young tennis players, leading to great pressure to practice, high expectations of performance and increasing demands on the human body (Mothadi and Poole 1996). Tennis requires a variety of physical attributes including speed, power, endurance, strength and balance and specific playing skills. Tennis places acute physical demands on players, requiring them to move quickly in all directions, change directions often, stop and start, while maintaining sufficient balance, control and upper body strength to hit the ball effectively (Chandler 1995). Therefore, participants should train and prepare to meet at least a minimum set of physical, physiological and psychological requirements to cope with the demands of play and reduce the risk of injury.

The aim of this report is to provide advice on the prevention of tennis injuries, through a critical review of the formal and informal research literature relevant to injury prevention. An overview of the epidemiology of tennis injury and a discussion of common tennis injuries are given to provide a background to the review of potential countermeasures to injury.

The recommendations have been based on the literature review and discussions with the experts acknowledged in this report. Many of the recommended countermeasures must be regarded as promising, rather than proven, and more controlled field evaluations of their effectiveness are needed. For example, the evidence on whether warm-up and stretching prevents injury remains equivocal. More research effort needs to be directed to epidemiological studies to determine the risk factors for injury and the role of the identified risk factors in causation and basic scientific studies to better understand the biomechanics of tennis and the mechanisms of injury.

PARTICIPATION AND INJURY DATA

A population household survey conducted by the Australian Bureau of Statistics (ABS) in 1995/1996 reported that 362,000 Australians over the age of 15 years participate in tennis. This ranked tennis as the third most popular sport and physical activity in Australia, behind aerobics and golf. More females (57%) than males (43%) play tennis. Over one-third (37%) of players are over the age of 45 years. Over one-half of all participants (55%) indicated that they participate in tennis once a week. The survey estimated that 114,300 Victorians participate in tennis (46% males and 54% females).

Emergency department presentations data collected by the Victorian Injury Surveillance System (VISS) indicate that tennis injury amongst adults (aged ≥15 years) and children (aged <15 years) accounts for 2% of all sports injury. Sixty-nine percent of tennis injuries to adults and 40% of injuries to children occurred during formal competition.

Injuries to adults in formal play were mostly to the lower limb (55%), particularly ankle and knee sprains and strains (15% and 12% of all injuries respectively). The upper limbs accounted for another 24% of all injuries, particularly fractures to the wrist (14%) and radius/ulna (9%). Overexertion (causing sprains and strains) was the most common cause of injury among adults during formal play.

Upper limb injuries were more common than lower limb injuries among children. Forty-five percent of all child tennis injuries in formal play were to the upper limbs, particularly fractures of the radius/ulna (7% of all injuries) and sprain/strains of the wrist (4%). Thirty-one percent of injuries were to the lower limbs, particularly ankle sprains/strains (28% of all injuries) and sprains/strains of the knee (24%). Nine percent of injuries were to the head and face.

Falls were the most common cause of injury to children during formal tennis play, accounting for 31% of all injuries. Children are probably more prone to fall injury than adults. Their skills, technique and co-ordination are less well-developed which causes loss of balance and falls, commonly onto an outstretched arm.

The incidence of injury in terms of body region and nature of injury reported from VISS data correlates to a large extent with that reported in the research literature. Sprains and strains are consistently reported to be the most common injury in tennis. Conclusions based on comparisons between the published epidemiological studies on tennis injury must be treated with caution, because of differences in study populations, data collection methods and injury definitions.

RECOMMENDATIONS FOR FURTHER COUNTERMEASURE IMPLEMENTATION, RESEARCH AND DEVELOPMENT

Playing technique

- Promote techniques that maximise bio-mechanical advantage and protect from excessive forces and overuse (based on current research evidence) through coaches, trainers and sporting organisations.
- Practice sessions should comprise a balanced variety of tennis strokes and other training activities.
- Rigorous epidemiological studies are required to adequately describe limb and back injuries in tennis and to investigate potential risk factors including exposure (both to training and play), playing technique and lack of physical conditioning.
- Further research is needed to expand current knowledge on the biomechanics of tennis play and associated risk of overuse injuries and investigate the optimal type and duration of training and conditioning that maximises skill development and fitness and minimises overuse injuries.

Physical preparation

Pre-participation evaluation

- Extend pre-participation screening and tailored pre-season conditioning programs to a wider group of serious players and evaluate the protective effects of these programs.
- Continue to research assessment measures that are tennis specific to improve pre-participation evaluation instruments.
- Systematically evaluate the injury prevention efficacy of the current pre-participation evaluation program for elite and squad tennis players.

Training and conditioning

- Simple pre-season fitness testing should be conducted on players participating in competitive tennis at the inter-club level, four to six weeks prior to the start of the season.
- All competitive and recreational tennis players are advised to undergo a graduated skills development and training program (which includes cross training), guided by results of an initial fitness test.
- Players should consult an accredited tennis coach on their individual training requirements.
- Initiatives to increase the awareness of players and coaches of the injury consequences of training errors (including over-training) should be continuously developed, and refined as new knowledge becomes available.
- Controlled evaluation studies should be conducted to determine 'best practice' conditioning and training programs that develop the skills and fitness necessary for competitive tennis and protect players from injury.

Warm up, stretching and cool down

- All players should routinely warm-up, cool down and stretch before and after every game and training session.
- The specific needs of the injured tennis player should be considered when warm-up, stretching and cool down regimes are developed.
- The injury protective effects of warm-up, stretching and cool-down require evaluation in controlled trials.

Environmental factors

Weather and player hydration

- Extreme heat policy and rules need to be developed at the local club and inter-club competition levels.
- Clubs should provide umbrellas and ice-chests on-court, and supply water and 'sports' drinks (with 4%-8% carbohydrate content).
- Players should learn how to monitor their fluid intake during games by weighing themselves or by noting any reduction in the amount and concentration of urine output in relation to fluid intake (oliguria). Players should replace fluid and electrolyte loss by consuming 400-600 mls of fluid (2-3 standard glasses) at least 30 minutes before play and 200-300 mls (1-2 glasses) every 15 minutes during play (at change of ends).
- Education and signage about measures to prevent heat illness should be provided at the club level.
- Players should use a broad spectrum sunscreen.
- Research should continue on player diet and hydration issues.

Playing surface and surrounds

- Risk management/sports safety plans, that include measures to eliminate or ameliorate environmental and other injury hazards, should be developed, implemented and monitored by tennis facility owners (including local councils, associations, clubs, schools and churches) and managers. Guidelines and support for the development of these plans should be available.

- Equipment, seating and advertising should be kept away from court boundaries, net posts should be padded.
- Tennis surfaces should be diligently maintained and regularly checked for hazards such as hollows, cracks and wear.
- Further laboratory and controlled field research is needed to determine the optimal safety performance values for tennis surfaces.

Playing equipment

Racquet selection

- Players, especially those with arm and shoulder symptoms, should seek professional assistance when selecting a racquet and choosing string tension.
- More epidemiological, biomechanical and independent laboratory research is needed to determine the impact of the size, shape, frame material, string material and tension of the racquet on the incidence of upper extremity overuse injury in tennis.

Ball choice

- Players should always match the ball type with the playing surface and climatic conditions.
- Players with arm symptoms should avoid playing with wet balls and in windy conditions.
- Players should limit play with used balls and avoid play with dead balls.

Footwear

- Players should choose their shoes carefully, preferably with professional advice on the most appropriate shoe for their foot type and the playing surface on which they mostly play.
- Tennis shoe manufacturers should provide more information to consumers at point-of-sale on suggested indications and playing surfaces for which their shoes are or are not recommended.
- Future research on tennis footwear must adjust for confounding factors, such as previous injury and exposure, when investigating the relationship between shoe construction and injury.
- The effectiveness of orthoses in the prevention and treatment of overuse injury should be determined by well-designed controlled studies that involve sufficient subjects to provide definitive results.
- Further research is needed to evaluate the protection against foot blisters afforded by the different kinds of tennis socks with the aim of developing design and material criteria.

Protective equipment

- Update epidemiological research into the incidence and nature of eye, facial and dental injuries in tennis and investigate risk factors and potential protective measures.

Graduated and modified training and games

- Children should be progressively introduced to tennis through the modified games program promoted by Tennis Australia and Tennis Victoria.
- Children should play tennis with an appropriate racquet, in terms of size and weight.
- As children progress from modified games to regular tennis, guidance should be sought from an accredited coach on a suitable training routine.

Education and coaching

- Accredited coaches should be available at every club to advise and monitor the skills development of players at every level (competitive and social).
- All coaches should be accredited and undergo the regular training and re-accreditation provided through Tennis Coaches Australia and state divisions.
- Continuous systematic evaluation of the effectiveness of education/training programs should be maintained.

Treatment and rehabilitation

- Event organisers and tennis clubs should ensure that there are qualified first aid personnel/sports trainers at all events and competition match days.
- Clubs should have a well-stocked first aid kit and a supply of ice-packs.
- Players should seek prompt attention for injuries from a sports medicine practitioner and allow enough time for adequate rehabilitation before returning to their pre-injury level of activity.
- Players with recurrent injuries should seek expert advice on appropriate taping or bracing and rehabilitation.
- Further research and evaluation of rehabilitation programs is required, to develop optimal regimes.
- Further controlled research is needed to investigate the efficacy of prophylactic taping and bracing in the prevention of ligament injury and re-injury in tennis.

GENERAL RECOMMENDATIONS

In addition to the specific recommendations in this report, the following set of more general recommendations are made:

- Improve data collection on the frequency, pattern and contributory factors to tennis injury. All data collections should conform to national guidelines for sports injury surveillance (the Australian Sports Injury Data Dictionary).
- Further epidemiological research is needed to determine the risk factors for tennis injury and to evaluate the effectiveness of countermeasures.
- Guidelines for minimum safety requirements for organised tennis (including the need for mobile phones, emergency telephone contacts and first aid kits) should be developed and widely disseminated.
- A cost of sports injury study is required to determine the overall cost of sports injury and the relative cost of injuries for different sports.

1. INTRODUCTION

Tennis is one of the most popular sports in the world. Every day it is played by millions of people of all ages at various standards. Participation in tennis provides the opportunity for developing physical fitness either in a highly competitive or a social atmosphere. Tennis is a ball and racquet sport and can be played as a singles (2 players) or doubles (4 players playing in teams of two) game. The game of tennis is characterised by hitting the ball with a racquet over the net and within the lines of play in order not to lose a point.

Tennis is believed to have originated with the ball games played by the ancient Greeks, Romans and Egyptians that were refined in the European royal courts, monasteries and streets over time. The introduction of simple racquets created faster and more skilful games. The French players called out ‘tenez’ to warn their opponents that they were about to hit the ball. The first tennis match in Australia was played in 1878 on an asphalt court at the Melbourne Club (Australian Sports Commission 1997). Royal tennis is played in Australia and elsewhere, however the modern game of tennis is the subject of this report. Today there are four major grand slam championships: the Australia Open, French Open, Wimbledon (British) and the United States Open. In 1997 these events attracted a total world-wide audience of 1,752,486 million. There are also a number of other highly competitive tournaments played around the world.

A significant amount of research on tennis injury has been published, predominantly on the epidemiology, biomechanics and treatment of tennis injuries. This has often included informed and expert conclusions on the causes of specific tennis injuries and how to prevent them. There is, however, a notable lack of formal, controlled evaluations of the effectiveness of tennis injury countermeasures.

2. AIMS

The aim of this report is to critically review the formal research literature and informal sources that describe the full range of injury prevention measures for tennis. The report provides an evaluation of the extent to which these countermeasures have been demonstrated to be effective.

This report does not focus on the epidemiology or aetiology of tennis injuries. Instead, it concentrates on providing a systematic and detailed examination of the range of countermeasures promoted to prevent tennis injuries. A brief overview of the epidemiology of tennis injuries, particularly from an Australian perspective, is given to set the scene for the subsequent discussion of countermeasures.

3. METHOD

The sources of information used to compile this report were:

- Medline CD-ROM search for published medical literature (since 1985)
- Sport Discus CD-ROM search for published sports literature (since 1985)
- Austrom: Ausport (Sport) CD-ROM search for published Australian sports literature (since 1985)
- Population Survey Monitor (PSM) of the Australian Bureau of Statistics
- Brian Sweeney and Associates market research into Australians and Sport 1996
- Discussions with personnel from state and national tennis organisations
- Scanning of internet and world wide web sites
- Expert comment on the draft report

This review is based largely on English-language material. Non-English language articles with English abstracts have been included in this review where appropriate.

Injury epidemiology is the study of the distribution and determination of injury-related states and events in specified populations and the application of this study to the control of injury problems. With regard to epidemiological studies, a scale has been developed to assess the quality of research evidence (Table 1). This scale reflects an epidemiological and rigorous scientific approach to injury prevention that considers demonstration of the effectiveness of a countermeasure's performance *in the field* to be the highest level of 'proof'. In general, the effects of changes to factors such as how the sport is played or undertaken and the behaviour of the participants and the equipment they use can only be measured during "in-the-field" evaluations.

Table 1: Grading scale for assessing the quality of research evidence

Relative strength	**TYPES OF EPIDEMIOLOGIC STUDIES**
Weaker	**DESCRIPTIVE STUDIES (case series and cross sectional)** **Case series (small, special registry and population-based)** **What are they?** Case series studies identify, define and describe injury problems and patterns. They classify injury cases into homogenous (like) subsets, count them, measure their severity and may specify their concentrations in specific population groups. There are three types of case series: • *Small* for example, cases drawn from a single hospital or a small group of hospitals; • *special registry* for example, the new Victorian Emergency Department Minimum Database which holds detailed injury data collected from 25 hospital Emergency Departments; and • *state or national data*, for example, studies based on the Victorian Inpatient (hospital admissions) Database (VIMD) which collects a small amount of data on injury cases from all public and private hospitals. **Example:** *A study of 300 tennis injury cases presenting to VEMD hospital emergency departments 1996-1997.* **Strengths and weaknesses:** Case series can be a rich source of information on injury, especially special registry studies. If the injury hazard from the case series is obvious, there may be little need to carry out more complex and expensive research. However, case series can't be used to specify causes of injury. Also, the sample of cases may be biased (particularly when drawn from small and registry-based collections) and not representative of all cases, which precludes the calculation of injury rates and trends over time. **Cross sectional studies (surveys)** **What are they?** These studies determine the status quo of a condition during a specified period of time, *for example*, a survey of injuries among a representative sample of tennis players. Most surveys are cross sectional. **Strengths and weaknesses:** Cross sectional studies examine the relationship between the condition (for example injury) and other variables of interest (for example age, gender, skill level, use of protective gear) by comparing the prevalence of the condition in different population subgroups and between those with or without the condition, according to the presence or absence of the variables. They examine a condition at one point in time so cannot determine cause and effect.

Stronger	**ANALYTIC (OBSERVATIONAL) STUDIES (case control and cohort)** **What are they?** These studies test hypotheses (suppositions/conjectures) about the influences which determine that one person is injured while another is not i.e., they provide strong evidence on the causes, risk and contributory factors to injury. • **Case-control studies** The researcher assembles a group of persons with the injury of interest (cases) and a comparison group without the injury under investigation (controls), *for example,* tennis players with and without ankle injury. The researcher then investigates the history of past (retrospective) exposure to one or more potential risk factors for the injury (for example previous ankle injury, tennis shoe type and use of ankle brace). **Strengths and weaknesses:** Case control studies generally require a comparatively short study period, are relatively inexpensive and have the ability to examine association of several risk factors for the given injury. However, the choice and recruitment of appropriate controls can be difficult. Because case control studies investigate retrospectively from the injury event they are subject to recall and other biases which may affect the results and weaken evidence of cause and effect.
	• **Cohort studies** The investigator begins with a group of persons exposed to the factor of interest and a group of persons not exposed (for example, 15 to 19 year-old males would be a suitable cohort if tennis injury was the factor of interest) and then follows up the cohort over a number of years and *observes* the association between exposure (tennis) and outcome (injury). **Strengths and weaknesses*:*** Because they are generally prospective (forward-looking) the likelihood of collecting reliable and valid data is greater. Consequently, results from a well-designed cohort study carry more weight in establishing a cause than results from a case control study. However, cohort studies often involve large numbers (especially if the factor of interest is rare) and/or long study periods and, therefore, are expensive. The other potential problem is the dropout rate ('loss to follow-up') which, if large, results in biased data.

<table>
<tr>
<td>Strongest</td>
<td>EXPERIMENTAL STUDIES
(Randomised controlled trial and community trial)

What are they? In experimental epidemiological studies, the investigator controls the conditions under which the study is to be conducted by assigning subjects (preferably randomly) to either an experimental (treatment) group which receives the intervention or a control group that does not receive it.

• Randomised controlled trial (RCT)

In a RCT the investigator randomly allocates similar persons to the treatment and control groups. For example, in a RCT to investigate whether or not wearing an elbow counter-force brace prevents tennis elbow, the subjects would be recruited into the trial and randomly allocated to the treatment group (who wear an elbow brace) or the control (non-wearing) group and followed-up over time to determine the effectiveness of the countermeasure.

• Community trials (quasi-experimental)

In a community trial the group as a whole is collectively studied. The investigator selects two similar communities. The incidence of the disease or condition of interest (for example mouth/teeth injury) and prevalence of suspected risk factor/s for which an intervention has been developed are surveyed in both. The intervention (for example compulsory wearing of mouthguards) is then carried out in one community and the other does not receive it. The communities are surveyed again. The net difference in the incidence of the condition and prevalence of the risk factor/s is thereby associated with the intervention.

Strengths and weaknesses: Well-conducted controlled trials, where the assignment of subjects or communities to the experimental or comparison group is random, are regarded as the strongest epidemiological studies and provide the greatest justification for concluding causation. Obstacles to their use include their great expense and the lengthy research period.</td>
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<td colspan="2">References:
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Another important aspect of countermeasure implementation is the extent to which they are accepted or adopted by the users for whom they were intended. Countermeasures should be acceptable to those they were designed to protect. Community consultation and awareness programs must therefore be considered in any implementation process. It is also important to assess barriers towards use of injury countermeasures. An examination of attitudes, knowledge and behaviours is crucial to this. Studies of these factors can highlight the need for behavioural or educational change at either the individual or organisational level. Because of the importance of this sort of research, any literature describing these studies is included in this review.

Another measure of the success of countermeasures is a demonstration of their benefit/cost ratios. This information is often required by policy and regulatory bodies to inform their decisions about implementation of injury countermeasures.

4. PARTICIPATION IN TENNIS

It is estimated from a series of household population surveys conducted between 1992 and 1996 that 28% of Australians over the age of 16 years participate in tennis (Brian Sweeney and Associates 1997). Female players outnumber males (53% versus 47%). The highest proportion of participants are aged over 45 years (46%), followed by 16-29 year olds (34%) and 30-44 years olds (20%). These estimates are based on data gathered from small samples of respondents in capital cities and restricted to persons aged over 16 years.

A larger population household survey conducted by the Australian Bureau of Statistics (ABS) in 1995/96 estimated that over the 12-month period 362,000 Australians over the age of 15 years participated in tennis. This ranked tennis as the third most popular sport and physical activity in Australia, behind aerobics and golf. Other results were similar to those reported by Sweeney (1997). More females participate than males (57% versus 43%) and the highest proportion of participants are aged over 45 years (37%). Over one-half of participants (55%) indicated that they played tennis once a week. The survey revealed that 114,300 Victorians play tennis (54% female, 46% male).

Comprehensive data on the participation of children and youths are lacking. In a recent New South Wales youth sports injury survey conducted in schools by the Health Promotion Unit, Northern Sydney Area Health Service, 20% of all respondents (12-19 year olds) reported that they participated in tennis. Tennis was ranked as the fourth highest sport in terms of participation behind basketball, soccer and swimming. Those surveyed participated in tennis within a club environment (32%), at school (24%) and for fun (44%).

RECOMMENDATION FOR COLLECTION OF PARTICIPATION DATA

- An agreed set of guidelines and format for collecting sports participation data should be developed.
- National sports participation data collections should include participants aged 15 years of age and under.

5. AN OVERVIEW OF THE EPIDEMIOLOGY OF TENNIS INJURIES

There are few good population-based studies that accurately show the incidence of injuries in tennis players (Kibler 1994; Mohtadi & Poole 1996). Information comparing competitive and recreational players is not readily available (Mohtadi & Poole 1996). Further, much of the published research and commentary has been devoted to tennis elbow.

Most studies are small and the populations closely defined so the injury rates and risks cannot be generalised to larger or different populations of tennis players. Many research reports lack information on exposure to tennis injury (for example, injury rate per 100 hours played) which would enable comparisons between studies on reported rates of injury.

5.1 FREQUENCY AND PATTERNS OF INJURY

Few definitive conclusions about the frequency, incidence and pattern of tennis injury can be drawn from the studies reviewed in this section because of differences in definitions of injury, study populations, age and sex of players, level of play, playing surface, and inconsistencies in method of reporting findings on such variables as incidence, type and severity of injury.

5.1.1 Elite adult players

In one of the better designed studies, Winge et al. (1989) reported the mean injury incidence per player to be 2.3 injuries/1000 hours of tennis (training and playing) in a prospective study of 13 randomly chosen Danish elite teams consisting of 8 players each. Injuries were self-reported on a standardised form during the 1984 outdoor tennis season. A pilot study of the methodology had shown a 95% concurrence with the actual number of injuries.

Eighty-nine players were followed throughout the season. All were Championship players, the best players were ATP ranked. Male players sustained significantly more injuries than female players (2.2/player/1000 hours of tennis compared to 1.1/player/1000 hours of tennis). Upper extremity injuries were more frequent (46%) than lower extremity injuries (39%). Shoulder injuries were the single most frequent injury accounting for 17% of all injuries. Back, elbow, hand and ankle injuries, each accounted for 11% of all injuries. The main types of injury were overuse (67%), strains (14%), blisters (5%) and fractures (2%). There are no comparable studies on elite adult tennis players in Australia or elsewhere.

5.1.2 Elite juniors players

Injuries that required physical or medical assistance were recorded for 1,440 participants at the United States Tennis Association (USTA) National Boys' Tennis Championships from 1986-1988 and from 1990-1992 by Hutchinson et al. (1995). Over the six-year period, a total of 304 players (21% of participants) suffered a new or recurrent injury that required evaluation by the medical team. Exposure was measured in terms of athletic exposures (AE), the total number of tournament matches played multiplied by the number of participants.

The incidence of injuries (new injuries) was 9.9 per 100 athletes, 21.5 per 1000 AE, the prevalence (new and recurring injuries) was 21.1 per 100 athletes. The incidence and prevalence of lower extremity injuries was approximately twice that of upper extremity injuries and the difference was statistically significant ($p=0.007$ and $P<0.0001$, respectively). The most common anatomic site of injury was the back (16% of all injuries) followed by the thigh, hamstrings, shoulder and ankle. Tennis elbow accounted for 6% of all injuries reported. Strains and sprains were the most common type of injury accounting for 71% of all injuries. The vast majority of ligamentous sprain injuries (88%) were to the knee and ankle. The authors concluded that young elite athletes are at significant risk of injury.

Reece et al. (1989) undertook a small retrospective review of the medical and physiotherapy records on 45 elite young male and female tennis players (aged 16-20 years) at the Australian Institute of Sport (AIS). The study reported 176 injuries to players over the four-year period between 1982 and 1985. Exposure data (playing hours) were not available. Women reported an average of 2.9 injuries each while the men reported 2.5 injuries each. Fifty-nine percent of injuries were to the lower extremities, 20% to the upper limbs and 21% to the trunk. Sixty-three percent of injuries were intrinsic, 34% overuse and 3% extrinsic. The most common intrinsic injury was an ankle sprain.

Kibler et al. (1988) studied the injury experience over the previous 18-month period of 97 elite junior tennis players (aged 13 to 19 years) from the United States, Sweden and England who played tennis between 11and 24 hours per week. An injury was defined as a condition lasting 5 or more days, that caused alteration in playing level performance or cessation of play. Sixty-five percent of players had experienced at least one such injury over the 18-months study period. Overload (overuse) injuries accounted for 63% of all injuries, traumatic (acute) injuries occurred 37% of the time. The shoulder and back were the most frequently injured body sites, followed by elbow, knee and ankle.

Baxter-Jones et al. (1993) followed up a group of 253 elite young athletes (231 boys, 22 girls) in five two-year age groups from 8-16 years to determine the incidence of self-reported injury among players of four sports. The proportion of players that were injured (determined from medical interview and medical examination data) in the four sports over the two-year follow-up period were: footballers (67%), gymnasts (65%), tennis players (52%) and swimmers (37%). However, these data included injuries in competition and training of the chosen sport and injuries from other sporting activity. Approximately two-thirds of the tennis injuries were acute (defined as onset from a single clearly remembered event) and one-third overuse (no clearly remembered onset event). Injuries were more likely to occur in training rather than competition. There was a fairly even distribution of tennis injuries over the whole body, although injuries to the ankles and feet were slightly more prominent (22%) than injuries to other body sites.

5.1.3 Non-elite adult players

A random British population-based postal survey of 16-45 year olds was conducted by Nicholl et al. (1991) over a one-year period to identify sport and recreation injuries. The incidence of injury for tennis was 2 injuries per 1,000 occasions of participation. This was less than other racquet sports such as squash (5 per 1,000) and badminton (3 per 1,000) and dramatically less than rugby, the highest risk sport (50 per 1,000).

Cunningham and Cunningham (1996) investigated the frequency of injuries at the 1994 Australian University Games that involved 5,106 amateur participants competing in nineteen sports over a six-day period. The standard of players was reported as a mix of experienced and inexperienced amateurs. Tennis was reported to have a comparatively low injury incidence (7% of registered tennis participants were injured) and frequency (12 cases) compared to the other sports played. The injury rate per 1,000 player hours was not reported for tennis. Sprains and strains accounted for just over one-half (53%) of the 15 tennis injuries that were reported during the Games.

Lanese et al. (1990) conducted a prospective study of eight matched men's and women's intercollegiate sports teams, including 23 tennis players, over one academic year to determine the incidence of athletic injury and resulting disability, including gender differences. Overall, 35% of tennis players suffered an injury (males 42%; females 27%). Expressed in terms of hours of exposure, this translated to 0.16 injuries per 100 person hours (1.6/1000 hours) for male tennis players and 0.1 injuries per 100 person hours (1.0/1000 hours) for female tennis players.

Chard and Lachmann (1987) conducted a retrospective study of 631 acute and chronic injuries seen in a sports injury clinic over the previous seven years due to the racquet sports of squash (59%), tennis (21%) and badminton (20%). The site of injury for tennis players (n=131) was lower limb (45%), upper limb (35%) and trunk (20%). The most commonly injured body parts were the knee (19%, predominantly patello-femoral pain and patella dislocation), back (16%, predominantly disc prolapse) and elbow (15%, predominantly lateral epicondylitis). Overuse injuries, such as tendinitis, accounted for 30% of all tennis injuries.

The one-year incidence of tennis elbow and other injuries among 260 regular tennis players (males 187; females 73) from the largest Western Australian lawn tennis club were reported by Kamien (1989). Retrospective injury data were obtained by postal questionnaire (86% response rate) and interview. Injuries were reported by 48% of all players (males 51%; females 40%). Shoulder, knee, back and ankle injuries accounted for 67% of all injuries among men and 32% of injuries among women. Injuries were mostly muscle, joint and ligament sprains. One or more injuries severe enough to prevent tennis play for longer than one week were sustained by 75% of injured males and 55% of injured females. The injury incidence in the 'severely' injured group was 0.51 injuries per person per year for men and 0.28 injuries per person per year for women. The one-year injury incidence of tennis elbow was 10%, marginally higher among men than women.

5.1.4 Non-elite junior players

In a NSW youth sports injury survey of 12-19 year olds conducted in schools by the Health Promotion Unit, Northern Sydney Area Health Service (1997), 9% of tennis participants reported an injury in the previous 12 months. The most common type of injury sustained during tennis participation was muscle strain (39%) followed by joint/ligament strain (34%) and bruising (24%). The most common sites of injury were the ankle (34%), knee (26%), and wrist (19%). Thirty percent of tennis injuries occurred during club competition, 21% occurred during training and 14% during leisure.

Backx (1991) conducted a longitudinal population based study of 1818 Dutch school children aged 8-17 years over a seven month period to determine the incidence and severity of sports injuries for different sports. Eleven percent of those surveyed participated in tennis. The injury incidence rate for tennis was found to be 147 per 1000 participants per year.

Reilly and Collyer (1995) studied the frequency and pattern of tennis injuries retrospectively for the previous year. One hundred (59 male and 41 female) players aged 9-18 years from 5 clubs in England were surveyed using a 32-item questionnaire. Altogether 51% of the junior players were injured (53% of males and 44% of females). Commonly injured tissues were the tendon (46%) and the muscle (29%). The most commonly injured body parts were the knee (20%), elbow (18%) and dominant shoulder (12%). A significant association was found between length of warm-up and occurrence of injury. A significantly lower injury rate was reported in those who warmed up for 5 minutes or more compared to those who did not. The protective effect of warm-up was said to be more pronounced for those who warmed up for 10 minutes or more but data were not reported. Overuse injuries were found to increase with the standard and duration of play. The highest injury incidence was in those practising for 16-20 hours a week. 'Training error' was the most common cause attributed to chronic injuries, whereas 'accidental' factors, such as tripping on court, were prominent causes of acute injuries.

5.2 AUSTRALIAN EMERGENCY DEPARTMENT PRESENTATIONS

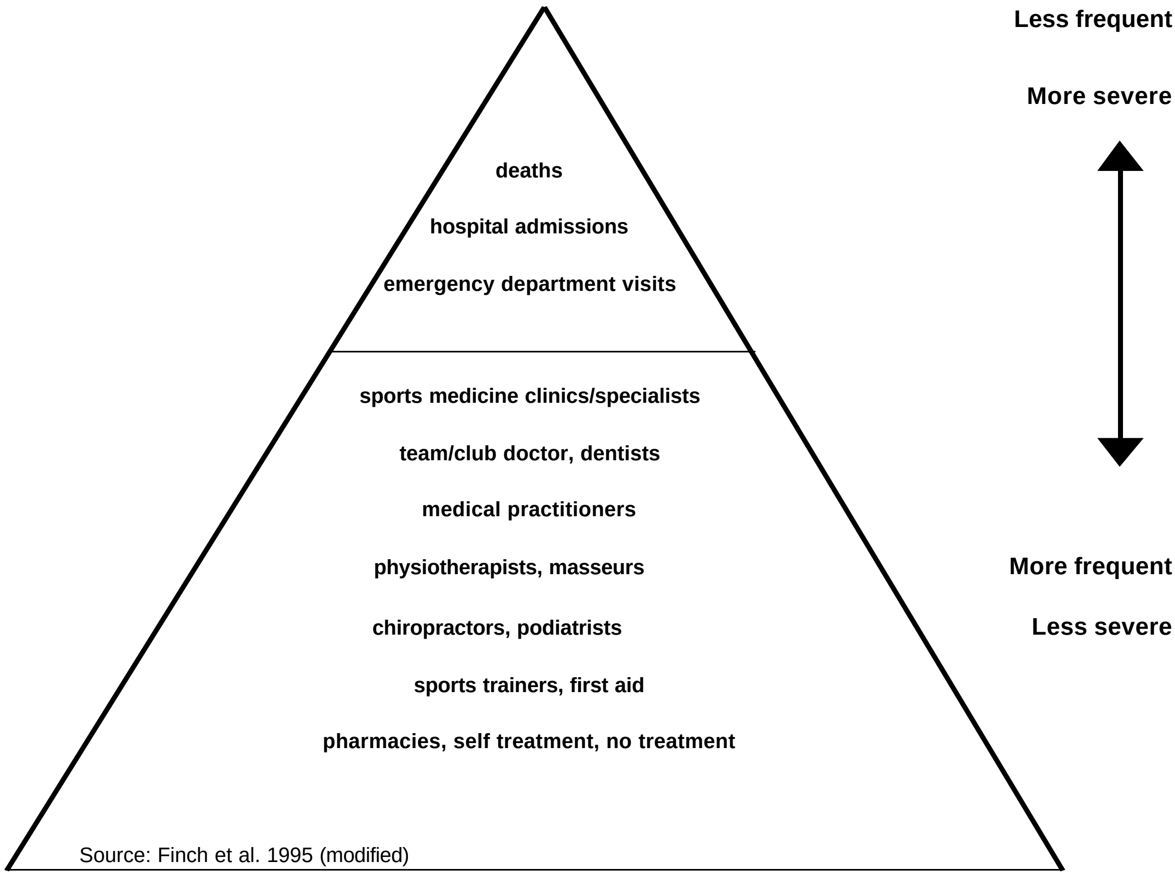
A study utilising Australian hospital emergency department presentations data found that tennis injuries amongst adults (aged >15 years) accounted for 2% of all sports injury cases (Finch et al. 1995). This ranked tennis as the fifteenth highest source of sports-related emergency department presentations. At the time of injury, 91% of cases were involved in tennis as a formal sporting activity (organised competition or practice: 73%; informal tennis: 10%; unspecified: 8%). The remaining 9% of cases occurred during recreational tennis activities.

Tennis also contributed 1% of all sports-related injuries to children, ranking it the fifteenth most common source of sports-related injuries leading to child emergency department presentations (Finch et al. 1995). Formal sport contributed 59% of all tennis injuries (organised competition or practice: 35%; informal games: 16%; unspecified: 9%). Recreational tennis activities accounted for 41% of all injuries.

Routley and Valuri (1993) reported similar findings for adult Victorians presenting to hospital emergency departments. They found that people injured while playing tennis contributed 2% of all sporting injury presentations and 6% of all sports-related admissions following emergency department presentation.

These studies are based on injury data from one place of treatment (emergency departments) so the findings on injury frequency and patterns are not representative of all tennis injury cases in the relevant populations (Finch et al. 1995). As is shown in Figure 1, injuries presenting to emergency departments usually fall at the 'less frequent, more severe' end of the injury scale. It is likely that the majority of tennis injuries would fall into the 'more frequent less severe' category and would be treated by a range of practitioners (for example doctors, physiotherapists, masseurs and sports trainers). There are currently no published data from these sources of treatment.

Figure 1: A sports injury pyramid



5.3 VICTORIAN EMERGENCY DEPARTMENT PRESENTATIONS

The Victorian Injury Surveillance System (VISS) holds information on injury presentations to Victorian public hospital emergency departments. The collection began in 1988 and data were progressively collected from 7 campuses of 5 public hospitals by 1992[1]. Since 1995, the more expanded Victorian Emergency Minimum Dataset (VEMD) has been introduced in 25 hospitals, 23 of which were contributing data at the time of analysis.[2] For the purpose of this report, data on tennis injuries have been combined from these two consecutive data systems. The combined data form a large case series but are not necessarily representative of all tennis injuries presenting to emergency departments. Most adult outdoor tennis injuries occurred during formal play whereas most child outdoor tennis injuries occurred during informal play (Table 2).

Table 2: Outdoor tennis injuries by age and type of game

Tennis type	Adult		Children	
	n	%	*n*	%
Formal	190	69	85	40
Informal/not specified	86	31	130	60
Total	276	100	215	100

Source: Victorian Injury Surveillance System, Emergency Department presentations 1988 to 1996

The patterns of tennis injuries among child and adult tennis players are summarised in tables 3 and 4.

1 Royal Children's Hospital, Western Hospital - Footscray and Sunshine Campuses, Preston and Northcote Community Hospital, Royal Melbourne Hospital and Latrobe Regional Hospital - Traralgon and Moe campuses

2 Alfred Hospital, Angliss Hospital, Austin and Repatriation Medical Centre, Ballarat Base Hospital, The Bendigo Hospital Campus, Box Hill Hospital, Dandenong Hospital, Echuca Base Hospital, The Geelong Hospital, Goulburn Valley Base Hospital, Maroondah Hospital, Mildura Base Hospital, Monash Medical Centre, Mornington Peninsula Hospital, Preston and Northcote Community Hospital, Royal Children's Hospital, Royal Victorian Eye and Ear Hospital, St Vincent's Public Hospital, Wangaratta Base Hospital, Warrnambool and District Base Hospital, Western Hospital, The Williamstown Hospital and Wimmera Base Hospital.

Table 3: Mechanism, body site, nature and severity of outdoor tennis injuries, ED presentations of children aged less than 15 years (*n*=215 cases)

	Formal tennis (*n*=85)		Informal tennis (*n*=130)		Total	
	n	%	*n*	%	*n*	%
Mechanism of injury						
- fall	26	31	19	14	45	21
- hit by racquet	11	13	36	27	47	22
- over-exertion	21	25	19	14	40	18
- hit by ball	8	9	24	18	32	15
- other	19	22	34	26	53	24
Body region injured						
- lower limb	29	32	27	21	56	25
- upper limb	41	45	49	37	90	40
- head and face	15	16	49	37	64	27
- other	6	7	7	5	13	6
Nature of injury						
- fracture	20	22	19	14	39	17
- superficial	18	19	37	28	55	24
- strain/sprain	38	41	33	25	71	32
- open wound	5	5	26	20	31	14
- other	12	13	17	13	29	13
Severity: hospital admission	4	5	11	8	15	7

Source: Victorian Injury Surveillance System, Emergency Department presentations 1988 to 1996.

Note: more than one injury may be reported per case

Table 4: Body site, nature, mechanism and severity of outdoor tennis injuries, ED presentations of adults aged 15 years and older (*n*=276 cases)

	Formal tennis *n*=190		Informal tennis *n*=86		Total	
	n	%	*n*	%	*n*	%
Body region						
- lower limb	105	54	40	47	145	53
- upper limb	44	23	27	31	71	26
- head and face	16	8	9	10	25	9
- other	29	15	10	12	29	14
Nature of injury						
- strain/sprain	81	42	36	42	117	42
- fracture	32	16	12	14	44	16
- superficial	36	19	15	17	51	18
- other	45	23	23	27	68	24
Mechanism						
- hit by ball	20	11	6	7	26	9
- slip/fall	42	22	13	15	55	20
- over-exertion	76	40	44	51	120	43
- hit by racquet	8	4	5	6	13	5
- other	44	23	18	21	62	23
Severity – hospital admissions	12	6	6	7	18	7

Source: Victorian Injury Surveillance System, Emergency Department presentations 1988 to 1996

Note: more than one injury may be reported per case

5.4 FORMAL TENNIS

Sixty-nine percent of adult and 40% of child tennis injuries occurred during formal outdoor competition. The circumstances of these injuries will be considered by age group and type of play.

5.4.1 Child Injury (*n* = 85 cases)

Most injured players (84%) were aged 10 to 14 years and 65% were male. Seventy-nine percent of injuries occurred in areas for organised sport, such as tennis courts, another 14% occurred at schools and 5% at parks. The major causes (mechanisms) of injury were falls/trips (39%), overexertion (25%), hit by the racquet (13%) and hit by ball (9%).

VISS can record up to 3 separate injuries per case. As a result there were a total of 93 separate injuries sustained by the 85 injured players. Forty-five percent were to the upper limbs, particularly fractures of the radius/ulna (8% of all injuries) and sprain/strains of the wrist (6%). Thirty-one percent were to the lower limbs, particularly strains/sprains of the ankle (9% of all injuries) and strains/sprains of the knee (9%).

The admission rate for children with tennis injuries was 5%. Forty-seven percent of injured children were treated without referral; 13% were referred to an outpatient's clinic; 7% required review in the emergency department; and 15% were referred to a general practitioner.

5.4.2 Adult Injuries (*n* = 190 cases)

Sixty-one percent of the 190 adult players injured while playing formal tennis were male. The age of players was fairly evenly distributed over the age groups up to 50 years of age. Eighty-five percent of injuries occurred at areas for organised sport and 13% at parks/recreational areas.

The major causes (mechanisms) of injury were over-exertion (40%), falls/slips (22%), and hit by the ball (11%).

VISS can record up to 3 separate injuries per case. There were 194 separate injuries sustained by the 190 injured players. Injuries to the lower limbs accounted for 55% of all injuries, particularly sprained/strained ankle and knee (18% and 9% of all injuries respectively). The upper limbs accounted for 24% of all injuries, mostly fractures to the wrist (5% of all injuries) and radius/ulna (3% of all injuries).

The admission rate for formal adult tennis injuries was 6%. Fifty-seven percent were treated without referral; 7% of players were referred to a general practitioner; 9% were referred to the outpatients department; and 12% were to be reviewed in the emergency department.

5.5 INFORMAL TENNIS

There were another 130 child and 86 adult tennis injuries which related to informal tennis play. These cases represent 60% of all child tennis injuries and 31% of adult tennis injuries recorded by VISS.

5.5.1 Child Injuries (n = 130 cases)

Three-quarters of child injury cases were aged 10-14 years and 62% were male. Twenty-eight percent of children's informal tennis injuries occurred at school. Other common locations for these injuries were home (27%), tennis courts (10%), parks/recreation areas (7%) and roads and streets (7%). In the remaining 21% of cases the location of injury was unspecified.

The most common causes (mechanisms) of injuries were: hits by the racquet (27%); hits by the ball (18%); falls (14%) and over-exertions (14%). VISS recorded 132 separate injuries. Thirty-seven percent of all injuries were to the upper limbs, mostly fractures of the radius/ulna (20% of all injuries) and elbow bruising (14% of all injuries). An equal proportion of total injuries (37%) were to the head/face, particularly cuts/lacerations to the head/face (14% of all injuries), bruising to the eye (3% of all injuries) and facial/head bruising (3% of all injuries).

The admission rate for these cases was 7%. Forty-two percent of injured children were treated without referral; 15% were referred to an outpatients department; and 8% to a general practitioner. Review in the emergency department was required by 10% of injured players, while the remaining 13% required no treatment.

5.5.2 Adult Injuries (n = 86 cases)

Sixty-two percent of adult informal tennis injury cases were males. Forty percent of these injured players were aged less than 25 years, although cases were fairly evenly distributes across the 5-year age groups up to age 50.

Thirty-eight percent of injures occurred at tennis court locations, 15% were at parks/recreational areas and 14% at home. In 29% of cases the location of injury was unspecified.

The major causes (mechanisms) of injury overexertion, falls/slips (15%), hit by the ball (7%) and hit by racquet (6%). Forty-seven percent of injuries were to the lower limbs, predominantly ankle sprains/strains (35% of all injuries) and knee strains/sprains (8% of all injuries). Another 31% of injuries were to the upper limbs, mostly shoulder dislocation (19% of total injuries) and 10% were to the face/head.

The admission rate for adults sustaining informal tennis injuries was 7%. Twenty percent of players were treated without referral. Referral to an outpatients department or general practitioner occurred in 17% of presentations respectively, while 15% required review in the emergency department and 13% required other referral.

5.6 CONCLUSION

The pattern of injury described from the analysis of Victorian hospital emergency department tennis injury data is reasonably consistent with that reported from other epidemiological studies, with the exception that, as is expected, there is a higher proportion of fracture cases in the VISS hospital ED tennis injury population (Table 5).

Table 5: Body region injured and nature of injury in tennis players, Victorian hospital emergency department data compared to published research (all ages)

	VISS data	Literature range
Body region		
Lower limb	32-54%	31-59%
Upper limb	23-45%	20-46%
Head & face	9-17%	2-7%
Nature of injury		
Fracture	16-22%	2-12%
Superficial	19%	10-19%
Sprain/strain	41-42%	25-71%

Assessing the level of agreement on patterns of injury between studies is difficult, because of the differences in study populations, methodology and presentation of data. An expanded and referenced table comparing published study results in terms of site and type of tennis injury is presented at Appendix 1.

However, irrespective of age and level of players, the studies included in this review generally report that:

- lower limb injuries are more common than injuries to other body regions;
- the most frequently occurring types of injury are sprains and strains; and
- between 5-11% of emergency department presentations require hospital admission.

Many of the published studies are retrospective and rely on self-reported information. Therefore recall of the injury in terms of cause, mechanism, site, diagnosis and recovery may be biased. The study samples were often small and confined to elite and skilled players, who are not likely to be representative of the general tennis population. The classification of age groups is also not always consistent.

The evident variations in the estimation of incidence (frequency) of injury in the studies may be attributed to variations in study definitions of the level and severity of injury, the training undertaken and the type of play undertaken (competition, recreational, training). Injury is not a desired outcome for any tennis player at competition or recreational level and effects can be serious in terms of impairment and disability. Consequently, injury countermeasures must be reviewed to identify those with the best potential for effectiveness and to form the basis for a comprehensive implementation strategy.

A comprehensive cost of sports injury study is required, based on high quality epidemiological data, to identify overall and relative costs of sports injuries.

6. SPECIFIC TENNIS INJURIES: EPIDEMIOLOGY AND AETIOLOGY

It is variously estimated that between 30% and 80% of tennis injuries are related to overuse, depending on the population studied (Reece et al. 1986; Chard & Lachmann 1987; Winge et al. 1989; Kibler & Chandler 1994; Ellenbacher 1995). The public exposure of professional tennis, and the vast amount of money involved, impact upon young tennis players, leading to greater pressure to train, higher expectations of performance and increasing demands on the human body (Mohtadi & Poole 1996). Therefore, an increasing number of overuse injuries can be expected because the hours of repetitive practice produce a gradual deterioration in the functional capacity of the body.

An overuse injury results from an accumulation of stresses to the involved tissue - bone, ligaments, muscles or tendons. According to Herring and Nilson (1987), the tissue and anatomic sites of an overuse injury may vary but the cause is the same: repetitive episodes of trauma overwhelming the body's ability to repair itself.

Overuse injuries are particularly likely to involve the upper extremity given the repetitive stroke technique required (Gecha & Torg 1988; Lehman 1988), including rotator cuff tendinopathy, tennis elbow and wrist problems (Nirschl 1988; Osterman et al. 1988). In the lower limb, injuries to the knees and feet are related to the constant pounding and associated ground reaction forces of the gait cycle that occurs during play (Leach 1988; Gecha & Torg 1988). Further, the spine and abdomen are also susceptible to injury, due to the twisting movement and associated transfer of impact forces (Balduini 1988; Lehman 1988; Marks et al. 1988; Mohtadi and Poole 1996).

Overuse injuries in tennis players usually begin with pain and stiffness. Continuous pain and stiffness eventually leads to a cessation of competition or training. Once an overuse injury develops, the condition remains until physiological equilibrium is re-established between the stresses of athletic activity and the body's healing ability (Ting 1991). Further, an overuse injury could be the result of a previous injury for which the body compensates, by increasing the stress on another part of the body. This eventually leads to tissue breakdown and overt injury at the vulnerable site.

6.1 UPPER EXTREMITY INJURY

The upper extremity is particularly susceptible to injury in tennis because of the use of the racquet, which acts as a lever, and the effect of repetitive stroke play on the dominant limb (Marks et al. 1988). Upper extremity injuries tend to involve the joint areas of the wrist, elbow and shoulder.

Nirschl (1994) suggested these factors contribute to upper limb injuries in tennis players:

- overuse (play exceeding three times per week; faulty technique and unsuitable equipment);
- age (35-55 years most common concerning tennis elbow and shoulder tendinitis);
- pre-disposing medical conditions (gout, oestrogen deficiency, hereditary mechanical issues);
- inadequate conditioning; and
- postural deficiencies.

6.1.1 Wrist injury

The major mechanism of wrist injury in racquet sports is persistent repetitive controlled force (causing tendinitis and other overuse injuries), although injuries can occur from direct trauma (for example, a fracture from a fall or a hit by a racquet) or from sudden, uncontrolled excess force (Osterman et al. 1988). The direct impact of the racquet handle and the repetitive forceful whipping of the wrist in stroke play cause a range of soft tissue injuries to players' hands and wrists (Osterman et al. 1988).

According to Kibler and Chandler (1994), wrist tendinitis is uncommon in tennis and is usually seen either in very advanced players who use more wrist motion to respond to hard shots or to create shots, or in beginners who use wrist motion because of poor stroke mechanics. Wrist biomechanics in tennis is not well studied. Blackwell and Cole (1994) investigated the wrist kinematics (flexion/extension), grip pressures, and wrist muscle electromyographic activity in 8 novice and 8 expert players performing the backhand stroke. The data gathered indicated that novice subjects eccentrically contracted their wrist extensor muscles throughout the stroke that may put them at risk of wrist tendinitis and lateral tennis elbow. Retting (1994) reported that during the service motion, approximately 10% of the force and 15% of the energy involved in the stroke is dissipated across the wrist joint. The service stoke also involves the greatest range of motion encompassing an arc of 90-100 degrees flexion/extension.

According to Retting (1994) the risk of wrist injury may be reduced by corrections to stroke technique and the selection of an appropriate racquet. He also recommends that injured players use a motion control brace.

6.1.2 Elbow injury

Elbow injury in tennis players has received the most research attention. Elbow injury is fairly common, usually related to overuse and may be chronic (Renstrom 1995). The most frequently occurring elbow injury in tennis players is generally referred to as 'tennis elbow' or elbow tendinitis/tendinosis (Nirschl 1992).

Both Carroll (1981) and Ellenbecker (1995) reviewed pertinent epidemiologic studies on upper extremity overuse injury among tennis players (Table 6). The proportion of players that reported having suffered elbow pain at some time during their playing career ranged from 35-57% in the seven different studies involving recreational adult players. The yearly incidence (new cases in a given year) of tennis elbow was 10.9% in the Winge et al (1989) study of elite adult players which is similar to the incidence of 10.4% reported by Kamien (1988) for club players. Ellenbecker (1995) drew attention to the studies by Priest and colleagues (Priest & Nagel 1976; Priest et al. 1980) that suggested an interplay and relationship between overuse injury in the elbow and shoulder among tennis players but Kamien (1988) found no association between tennis elbow and any other muskuloskeletal injury in the players he studied.

Table 6: Reported frequency of overuse elbow injury amongst tennis players

Population	Age	Sample size	Proportion reporting elbow injury (%)	Reference
Elbow				
Recreational adults	-	231	47 (career prevalence) 28 (point prevalence)	Priest et al. 1977
Recreational adults	-	200	50 (career prevalence)	Nirschl et al. 1977
Recreational adults	17-54	74	35 (point prevalence)	Carroll 1981
Recreational adults	-	2,633	31	Priest et al.1980
Recreational adults	-	534	38	Hang & Peng 1984
Recreational adults	-	150	41	Kitai et al. 1986
Recreational adults & children	10-79 male: mean 47.7 female: mean 39.3	260	57 (career prevalence) 10 (12 months incidence)	Kamien 1990
Danish elite professionals	14-48	104	11 (12 months incidence)	Winge et al. 1989

Source: Carroll (1981) and Ellenbecker (1995), modified.

Notes: The term 'incidence' is used loosely in the published literature. Strictly speaking it should be used to indicate the number of new cases within a given population in a defined period of time (e.g. 12 months). If new and ongoing cases are counted, then the correct term is 'prevalence'. Point prevalence refers to the number of persons with the condition in a given population at a specific point of time (for example, the time of the survey). Career prevalence refers to the number of persons who have had the condition at any time in their tennis playing career up to and including the time of the survey. In the table these figures are expressed as proportions (%).

Definition

'Tennis elbow' is not a clear-cut condition nor is it one specific type of injury. Kamien (1990) defined the condition broadly as '*pain on any side of the elbow which causes discomfort or disability when playing tennis or engaging in other sports or occupational pursuits*'. Typically the affected person complains of lateral elbow pain that is aggravated by gripping and interferes with activities of daily living, leisure pursuits and work. Allander (1974, cited in Noteboom et al. 1994) reported that 'tennis elbow' affected 1-3% in a population study of rheumatic diseases and conditions among 15,000 subjects, the proportion varying in different groups.

'Tennis elbow' is not confined to players of racquet and other sports that involve repetitive actions. In fact, the condition is predominantly found among manual workers engaged in repetitive work and has been shown to be associated with other activities that involve repetitive actions such as house painting and other home maintenance and Do-It-Yourself (DIY) tasks, gardening and hobby activities (Chard & Hazleman 1989; Renstrom 1995). Renstrom (1995) estimates that only 5% of 'tennis elbow' cases presenting to clinicians are related to tennis play.

Among tennis players the most common 'tennis elbow' condition is lateral tennis elbow tendinitis/tendinosis (also called lateral epicondylitis) of the dominant arm, primarily a pathologic alteration of the extensor carpi radialis brevis (Nirschl 1992). This condition is characterised by ligamentous pain and tenderness localised over the lateral elbow, that can radiate distally into the forearm, which is aggravated by the radial extension of the wrist (Nirschl 1992). Pain is usually experienced when the injured player executes a backhand stroke and/or serves (Kamien 1990; Renstrom 1995).

Medial tennis elbow tendinitis/tendinosis (medial epicondylitis) is a less common ‘tennis elbow’ condition among tennis players. It most frequently involves the pronator teres, the flexor carpi radialis and the palmaris longus, all of which originate at a common site on the medial epicondyle (Nirschl 1992). The ratio of occurrence of lateral to medial epicondylitis among tennis players is variously estimated to be between 3 and 7:1 (Roetert et al. 1995; Kamien 1988).

Some studies report medial tennis elbow as more prevalent among high-level tennis players, related to their vigorous service (Lemaire & Hotermans 1983; Reece et al. 1986). However, Kamien (1988) reported a relatively high prevalence of medial elbow pain (30%) among the 260 Western Australian club-level players in his survey. Pain is usually produced with the forehand, serve or overhead stroke (Nirschl & Sobel 1994; Kibler & Chandler 1994; Leach & Miller 1987).

Posterior tennis elbow, the third type, is comparatively rare, and reportedly accounts for just 2% of tennis elbow conditions in tennis players. It mostly involves the triceps tendon (Nirschl 1992).

Symptoms

Tennis elbow is generally attributed to mechanical overuse, however the onset of symptoms may be sudden or gradual. Kamien (1990) hypothesises that those who report acute onset of pain have suffered a moderate to major tear at the junction of tendon and bone, while gradual onset cases (where pain reaches a peak 24-72 hours after activity) have experienced microtears in the same region. He pointed out, however, that this explanation is weakened by the evidence from his own research that the prognosis for sudden onset cases was not consistently worse than that for gradual onset cases.

Aside from pain during and after games of tennis, the affected player may also experience weak grasp and pain in activities of daily living such as shaking hands, holding a cup of coffee, turning door handles and shaving. In serious cases, the player cannot play tennis or use the affected arm for activities involving gripping, turning and repetitive hand and arm movements (Kamien 1990).

Most affected players only experience one episode in their tennis-playing career. There is considerable variation in the recurrence rates reported in the literature. Kamien (1988) reported a recurrence rate of 12% whereas an earlier study by Gruchow and Pelletier (1979) found that tennis elbow recurred in 20% of cases.

Aetiology

Although ‘tennis elbow’ (elbow tendinitis/tendinosis) has received more research attention than other tennis injuries, there are still large gaps in knowledge about its pathophysiology and aetiology (Renstrom 1995; Kamien 1988; Kamien 1990). Based on evidence from pathological examination of operative material, it is now generally accepted that ‘tennis elbow
macroscopic and microscopic tears in the musculotendinous structures over and around the lateral and medial epicondyles of the humerus (Kamien 1990; Ollivierre & Nirschl 1996; Renstrom 1995). It is also well accepted that the condition is due to the overuse generated by the impact between racquet ad ball. The lesions are mostly sited at the tendonous origin of extensor carpi radialis brevis (Ollivierre & Nirschl 1996).

Kamien (1990) identifies a number of rarer causes of elbow pain reported in the literature including bursitis, inflamed synovial fringe from the elbow joint, strain on the elbow ligaments, calcific tendinitis and compression of the radial nerve. He states that there are well over 100 other causes of elbow pain, most of which are classified in a textbook by Wadsworth (1982) and are readily diagnosed by a competent doctor.

There are two alternative theories in the literature on how tennis elbow develops (Renstrom 1995). Some authors attribute the condition to repeated stresses caused by torque (ie. the twisting motion of the racquet in the hand when it hits the ball especially if hit off-centre). Others theorise that it is mainly due to the impact-induced vibration of the racquet-and-arm system at ball contact.

Renstrom (1995) reviewed the relevant laboratory studies and concluded that the most likely contributor is racket torsion from miss-hits (off-centre shots) that result in increased lower arm muscle activity. He was not convinced that the vibration experienced at the level of the elbow in tennis players was strong enough and of sufficiently low frequency to cause damage to the elbow.

In evidence he presented findings from a number of studies on the level of vibration in the hands and arms in people who work with hand-held power tools. These studies have consistently found that lower frequency vibrations (20-50 Hz for palm grip) travel up the arm whereas higher frequency vibrations (above 100 Hz) remain in the hand (Suggs et al. 1977; Cundiff 1974 and Reynolds et al. 1982, all cited in Renstrom 1995). The vibration that results from the impact of tennis racquet in the hand hitting a ball is, characteristically, of high frequency usually measuring above 100 Hz (Brody 1989). Renstrom (1995) found from his own (unpublished) experimental work that most of the vibration from the racquet stays at the level of the hand. His findings confirmed those of Hennig et al. (1992). Renstrom concluded that it was most likely that vibration does not cause tennis elbow pain syndrome but may have a role in aggravating the condition in the injured player (Renstrom 1995).

Notably, the research study by Hennig et al. (1992) is usually cited to support the argument that racquet-ball impact vibrations cause the microtrauma associated with ‘tennis’ elbow. In a laboratory experiment, Hennig et al. (1992) measured arm vibration caused by tennis racquet oscillations by fitting miniature accelerometers at the wrist and elbow in 24 tennis players (19 male, 5 female) who played two simulated backhand strokes (hitting the ball centre and off-centre with each test racquet). The players were of different levels of experience and 23 different commercially available tennis racquets were investigated. Amplitude, integrals and fourier components were used to characterise vibration.

The authors found a substantial (four-fold) reduction in vibration between wrist and elbow indicating large shock attenuation across joints. However, peak-to-peak acceleration values were approximately three times greater in off-centre impacts compared with centre ball impacts indicating that hitting accuracy is a substantial influence on the level of arm vibrations. Arm vibration levels were influenced by body weight and the skill level of players. There were increased vibration loads on the arm of less skilled players compared with proficient players across all racquets. Also, almost threefold differences in acceleration values between different racquet constructions were found - increased racquet head size and higher resonance frequency of the racquet were found to reduce arm vibration. The authors concluded that appropriate racquets, good hitting accuracy and playing experience were the major factors influencing the level of arm vibration caused by racquet-ball impact.

Pathophysiology

Nirschl (1992) argues that the more accurate description of chronic ‘tennis elbow’ is tendinosis, rather than tendinitis, because histologic examination of the pathologic tendon tissue does not characteristically show inflammatory cells. The lack of inflammatory cells also led him to theorise that the aetiology of the condition is mechanical, and is degenerative rather than reparative. He describes the core pathologic change as angiofibroblastic tendinosis, a failed healing response, where the normally orderly tendon fibres are disrupted by an invasion of fibroblasts and vascular granulation-like tissue which, in severe cases, also extends into the supportive tissue around the tendon itself. The affected tissue is dull, grey, friable and often endematous. This pathological tissue may result in rupture of the tendon and secondary fibrosis in severe cases. Tendinosis can appear in multiple sites in approximately 15% of cases and is then called Mesenchymal Syndrome.

Kamien (1990) found it difficult to reconcile the labelling of tennis elbow as a degenerative condition with the evidence on recurrence from his own and other epidemiological studies. He found that most players get tennis elbow at a mean age of 45 years, yet rarely get a recurrence even if they make no change in the frequency of their tennis activity.

Nirschl (1992) described four pathologic stages of tendinosis: temporary irritation (stage I); permanent tendinosis – less than 50% tendon cross section (stage II); permanent tendinosis - more than 50% tendon cross section (stage III); and partial or total rupture of the tendon (stage IV). He advised that a surgical solution is generally required for stages III and IV. He used patients' description of time and intensity of pain to develop a seven-phase table of pain that he correlates with the four stages of the tendinosis. For example, constant rest pain (dull aching) and pain that disturbed sleep and ranked 5 and above on a 10-point pain severity scale indicates stage III or IV tendonosis.

Risk factors and prevention

There have been no controlled epidemiological studies to definitively establish independent risk factors for 'tennis elbow' among tennis players. A range of potential risk and contributory factors have been suggested including: sex, age, inexperience, high playing time, faulty technique and racquet characteristics.

Sex and age

Epidemiological studies (mostly retrospective surveys) have consistently reported no significant difference in the prevalence of tennis elbow between men and women (Kamien 1988). Another consistent finding from these surveys is that older players (aged over 35 years) who have played over a longer length of time are more at risk of tennis elbow (Gruchow & Pelletier 1979; Hang & Peng 1984 both cited in Maylack 1988; Kamien 1988). In the most recent survey, Kamien (1988) found that club players who had a history of tennis elbow (mean age – male 50.5 years, female – 43.5 years) were, on average, seven to eight years older and had played three to four years longer than those without tennis elbow. The author comments that this result was not unexpected because of the greater length of exposure of the elbow to tennis strain among older players. He states that one of the many unresolved questions about the aetiology of tennis elbow is why the incidence peaks between the ages of 40 and 50 years yet the condition does not recur in most affected players. His study did not find that affected players gave up the game.

Faulty technique

Both Hang and Peng (1984) and Kamien (1988) found that beginning tennis play at an earlier age (in the second rather than the third decade of life) appeared to be protective against tennis elbow. Hang and Peng (1984) hypothesised that early starters learn better stroke techniques. It has been suggested from early surveys that faults in service and backhand techniques are implicated for symptoms of medial 'tennis elbow' and lateral 'tennis elbow', respectively (Carroll 1981; Renstrom 1995). Kamien (1988) used both independent expert observers and self-reported data in an attempt to 'test' the association between occurrence of tennis elbow and faulty stroke technique in a retrospective study of tennis elbow in 260 long-time tennis players. The forehand, backhand and service stroke techniques of a random selection of affected and unaffected players were observed 'blind' by two independent, high-level coaches who were acknowledged international experts in the scientific analysis of tennis stroke techniques. The two coaches were unable to accurately predict 45% of self-reported tennis elbow cases. The author also found that there was no association between the occurrence of lateral and medial 'tennis elbow' and respondents' self-reports about the type of strokes they usually used on both the forehand and backhand (Kamien 1998).

Playing time and concurrent repetitive activities

There is conflicting evidence on the impact of high playing time. Gruchow and Pelletier (1979, cited in Maylack 1988) reported from their retrospective survey of 568 US club players that playing time of more than two hours per day increased the incidence of tennis elbow from 7 to 18 cases per 100 population per year. In a study of 2,633 recreational players, Priest et al. (1980, cited in Renstrom 1995) found that the incidence of tennis elbow increased with playing frequency. In contrast, Kamien (1988) reported from his study of 260 club level players in Western Australia that there were no significant differences between players with a history of tennis elbow and players with no history, in terms of the frequency and hours of play per week or on any one day.

Kamien (1988) also found that women who engaged concurrently in tennis and other repetitive hand activities such as knitting, macrame and gardening were at a significantly higher risk of tennis elbow compared to their female tennis playing counterparts ($p<.01$). He found no other statistically significant correlation between the occurrence of tennis elbow and other concurrent repetitive activity (playing squash, golf or other hobbies/home maintenance activities), although he reported later that the correlation between occurrence of tennis elbow and concurrent regular squash play just failed to reach statistical significance (Kamien 1989).

Racquet characteristics

Racquet characteristics such as the material composition (wooden, aluminium or graphite), size (oversize), weight (heavy), grip size (too large or too small), and type of strings (gut or synthetic) and their tension have been reported to be associated with the development of tennis elbow. However, the epidemiological evidence implicating any of these factors is lacking or contradictory (Renstrom 1995; Kamien 1988).

Kamien (1990) comments that it appears from the evidence that different types of racquets seem to affect different players. In his study, 15% of the 110 club players whom self-reported having suffered tennis elbow at least once attributed it to changing to a new racquet (Kamien 1988). He also reported that 90% of the 60 affected players who had tried to alleviate their elbow pain by making one or more changes to the type of racquet they used (which involved 14 different combinations and permutations overall) claimed the change had been helpful. Racquet-related factors are dealt with in more detail in the countermeasures section that deals with equipment (section 8.4)

Treatment and rehabilitation

'Tennis elbow' is mostly a self-limiting condition. It usually resolves spontaneously, particularly if the affected arm is rested for several weeks. There is no agreement on the most effective treatment of persistent cases (Olivierre & Nirschl 1996; Renstrom 1995; Kamien 1990). A fuller discussion of treatment and rehabilitation of tennis elbow is in Appendix 2.

Non-operative (conservative) treatment

Kamien (1990) believes that rational treatment is hampered by the complexity of the condition, the fact that most reported cases are caused by occupational injury and the lack of controlled studies evaluating the various treatments.

Based on their clinical experience and research knowledge, Olivierre and Nirschl (1996), Renstrom (1995) and Kamien (1990) advise that the treatment of inflammation should follow the principles of PRICEMM (protection, rest, ice, compression, elevation, medication and modalities).

Kamien (1990) describes rest, sufficient to alleviate most pain and allow healing, as the cornerstone of treatment. A number of clinicians give qualified support for the use of steroidal injections (cortisone) to relieve persistent symptoms after trauma, provided only two or three injections are given (Kamien 1990; Olivierre & Nirschl 1996; Wadsworth 1987; Leach & Miller 1987). However, Kamien (1990) found no conclusive evidence in the literature that cortisone was more effective than more conservative (less invasive) therapies. Other modalities described by Olivierre and Nirschl (1996) as the 'most useful' in the treatment of tennis elbow are ultrasound and high voltage electrical stimulation. The authors were subsequently criticised by Stalker (1998) for failing to make reference to the previously published adverse review of these treatments by Labelle et al. (1992) and the adverse findings on the effectiveness of ultrasound by Gam and Johannsen (1995).

Kamien (1990) reported that his literature search found only one case control study on the effectiveness of acupuncture. This early study (Brattberg 1983) found acupuncture treatment was completely effective in 62% of resistant cases and significantly more effective than steroid therapy (cortisone). No patients in the acupuncture treatment reported adverse effects. Renstrom (1995) cited later double blind studies by Haker (1991) that found that acupuncture was the 'method of choice in the treatment for lateral epicondylitis' (*p.170*). Kamien (1990) is sanguine about patients with recalcitrant tennis elbow turning to any of the range of less conventional methods that have reported some success (laser-acupuncture in combination, chiropractic, vitamins B or C, electrogalvanic stimulation, transcutaneous stimulators etc.) provided they are non-invasive and do not result in any treatment-related morbidity. However, the cost (to the patient and the health system) of the continued use of unproven treatments needs to be considered.

LaBelle et al (1992) abandoned a planned meta-analysis of the scientific evidence on the treatment of 'tennis elbow' because of the general poor quality of the published studies and study variations which precluded the pooling of data. Instead, the authors subjected the 18 studies that described a therapeutic trial with a concurrent control group to a qualitative analysis. Their general conclusion was that there was insufficient scientific evidence to support any of the current popular methods of treatment for acute lateral epicondylitis i.e. ultrasound, ionisation; non-steroidal anti-inflammatory drugs (NSAIDs); and steroids. They called for large, well-designed controlled clinical trials that use double blind methods (where both the observer and the subjects are blind to whether the subjects are in the treatment or control group) wherever possible.

A Cochrane Collaboration systematic review of treatments for tennis elbow will be published in 1999 (http://hiru.mcmaster.ca/cochrane/).

Rehabilitation after conservative treatment

It is generally recommended that patients undertake a supervised, progressive and controlled program of isometric exercise (static muscle contraction) without a load and isotonic exercise (muscle movement performed at a constant level of muscular tension) after all the initial symptoms of inflammation have subsided (Olivierre & Nirschl 1996; Renstrom 1995; Kamien 1990). The aim is to restore the strength, flexibility and function of the muscles around the elbow to their pre-injury state and recondition the muscles of the forearm and shoulder before graduated return to play (Olivierre & Nirschl 1996; Renstrom 1995; Kamien, 1990). Kamien (1990) reported from his own research and two earlier epidemiological studies that 48-89% of patients self-report that exercise aided their recovery (Kamien 1988; Gruchow & Pelletier 1979 and Priest et al. 1980, both cited in Kamien 1990).

Attention to correcting faults in playing technique (especially the serve and backhand strokes) and to the type, weight, balance, string tension and grip size of the player's racquet are also recommended components of the rehabilitation process (Renstrom 1995; Kamien 1990). However, both Renstrom (1995) and Kamien (1990) report conflict in the literature regarding the association of racquet materials, weight and stiffness with the occurrence of tennis elbow.

The healing time can be long. Tennis elbow may cause pain for 1 to 72 weeks with a mean of about 36 weeks (Renstrom 1995; Kamien 1990). Because of the long treatment time and limited treatment alternatives, persistent elbow problems are frustrating for both the patient and the doctor (Renstrom 1995). The natural history of the condition is favourable to eventual recovery, without recourse to surgery, in over 90% of players who sustain an episode of tennis elbow (Kamien 1990; Renstrom 1995; Noteboom et al. 1994).

Operative treatment

Surgery is consistently viewed by clinicians as the therapy of last resort employed, as a general rule, only if failed healing is evident after 12 months of treatment and quality rehabilitation. Failed healing is signified by persistent pain even at rest, weakness and non-acceptable behavioural modification (Olivierre & Nirschl 1996; Renstrom 1995; Kamien 1990; Field & Altchek 1995). Wadsworth (1982) recommends manipulation as the treatment of last resort prior to surgery and reports that his use of the Mill's manipulation technique (with the patient under general anaesthesia) had successfully 'cured' most of the 100 resistant cases of tennis elbow he had treated over a 20-year period.

Kamien (1990) emphasises that tennis elbow is almost always self limiting and recommended surgery in only two circumstances: 12 months of failed conservative therapy with a level of pain that limits activities of daily living; or 6 months of unsuccessful conservative therapy in a 'well-balanced' patient who is pessimistic about the ultimate outcome of further conservative therapy.

Both open and closed surgery to relieve tension on the origin of the common extensor muscles (especially extensor carpi radialis brevis) by excising pathological tissue are practised (Kamien 1990). The proponents of the various techniques advocate them on the basis of different views on the causes of the condition (Noteboom et al., 1994). Kamien (1990) reviewed the literature comparing the outcome of open and closed surgery and concluded that the simpler closed procedure should be the preferred option (because it can be performed in the surgeon's office with the use of local anaesthesia) but noted that surgeons were usually antipathetic to 'blind' operations.

Rehabilitation after surgery

The elbow is protected in an immobiliser for approximately one week after surgery and gentle active range of motion exercises are begun in the second week. The post-operative rehabilitation program is the same as that for non-surgical care of tennis elbow. Return to full elbow strength is gradual and patients are advised to wait for 6 months after surgery before returning to full tennis participation (Olivierre & Nirschl 1996).

There are no controlled trials in the literature on the efficacy of counterforce bracing in the treatment of tennis elbow. Kamien (1990) reported that a number of descriptive studies have supported the proposition that the forearm counterforce brace is an effective adjunct to therapy, although there is some contrary evidence in the literature. Epidemiological studies by Nirschl (1974), Gruchow and Pelletier (1979), Priest et al. (1980) and Kamien (1988) found bracing to be helpful in relieving pain in 75-89% of players, based on player self-reports. The forearm counterforce brace was shown, via electromyography and 3-dimensional cinematography, to reduce stress on the elbow joint in a laboratory study conducted by Groppel and Nirschl (1986). The brace produced lower muscular activity in the extensor muscles (when serves and backhand strokes were played) and reduced angular acceleration at the elbow (when backhand and forearm strokes were played).

6.1.3 Shoulder injury

Shoulder pain is a common complaint among tennis players. Lehman (1988) found that nearly one-quarter of 270 competitive junior tennis players (aged 12-19 years) participating in the US junior tennis program had a current or past episode of shoulder pain and reported an incidence as high as 50% in some older age groups. The most common shoulder injuries are reported to be injuries affecting the anterior rotator cuff muscles and the supraspinatus tendon close to the insertion into the head of the humerus (Kamien 1988)

Frequency

Estimates of the frequency of shoulder pain among tennis players vary from study to study reflecting differences in sample sizes (many are small), tennis populations, methodology (including definitions) and study design limitations. Reports on the proportion of players with shoulder pain (current and/or past depending on the study) ranged from 8-30% among elite junior players and 7-45% among adult players (Table 7).

Table 7: Reported frequency of shoulder injury among tennis players

Population	Age	Sample size	Proportion reporting shoulder injury (%)	Reference
Shoulder				
Elite juniors	16-20	66	8	Reece et al.1986
Elite juniors	11-14	97	14	Kibler et al. 1988
Elite juniors	12-19	270	24	Lehman, 1988
Elite juniors	14-17	23	30	USTA (unpublished data, cited in Ellenbecker 1995)
Danish elite professionals	14-48	104	17	Winge et al. 1989
Competitive	-	2 481	9	Nigg et al.1986
Competitive/recreational	10-60+	260	8	Kamien 1989
Recreational adults	25-55+	2 633	7	Priest et al. 1980
Recreational (physiotherapy students)	-	372	45	Lo et al.1990

Source: Ellenbecker (1995) modified.

Aetiology

The aetiology of shoulder pain appears to be multifactorial and is still the subject of debate and investigation. The conditions that cause shoulder symptoms are usually classified according to the mechanism of injury to the shoulder – primary impingement syndrome (compressive tendinitis); primary tensile overload (tensile tendinitis); impingement and overload secondary to shoulder instability; or macrotrauma resulting from a direct blow to the shoulder (Blevins 1997). Macrotrauma is unusual in tennis and will not be discussed further.

The conflict in the literature revolves around which of the overuse pathologies is the primary cause of the majority of shoulder tendinitis and the sequence of degeneration to rotator cuff injury. A number of investigators propose that the much of the shoulder pain in tennis players, especially young players, is caused by subacromial impingement syndrome and shoulder instability (Lehmann 1988; McCann & Bigliani, 1994; Ticker et al. 1996). Nirschl (1992) contends, however, that in the majority of cases, particularly in young athletes, the primary condition is tendinitis caused by tensile overload with impingement a secondary condition. However, it is generally accepted that these shoulder pathologies may co-exist and are often inter-related.

Shoulder tendinitis (tensile tendinitis)

On the basis of his own surgical observations and clinical experience, Nirschl (1992) contends that tennis-induced shoulder tendinitis occurs mostly in the supraspinatus tendon and is caused primarily by intrinsic musculotendinous overload, just as in other body areas (for example, the elbow). He discounts the concept that subacromial impingement is the primary condition in the majority of cases of rotator cuff tendinitis, especially in young athletes, because he has only found a acromial variant sufficient enough to cause primary impingement in 10% of his patients, usually aged 50 and over.

Nirschl (1992) proposes the following continuum of rotator cuff pathology: eccentric loading of supraprinatus tendon➔fatigue and weakness➔inflammation, vascular compromise, permanent tendon change (angiofibroblastic degeneration) with occasional progression to rupture➔loss of humeral head control and upward humeral migration➔secondary impingement➔subteldoid bursitis➔fibrosis with progression to rupture➔humeral greater tuberosity exotosis and/or erosion; subacromial exotosis➔acromial osteoarthritis commonly noted after the fifth decade.

Tensile tendinitis can occur in the tendons of the biceps, triceps, pectoralis major, latissimus dorsi, teres major and teres minor (Allingham 1995). The affected tendon must be identified so that an appropriate treatment and rehabilitation regime is applied.

Subacromial impingement syndrome

Subacromial impingement syndrome (sometimes referred to as 'swimmer's shoulder) is defined as a musculo-tendonous overuse injury in athletes (and non-athletes) who make repetitive movements of the arm/s at or above the horizontal position. There is direct compression forces that cause mechanical trauma (impingement lesions to the superior aspects of the rotator cuff) in addition to any tensile lesions caused by overloading (Allingham 1995). First described by Neer in 1972, the condition is attributed to the repeated pinching, by the overhand motion, of the soft tissues (most commonly the tendons of the biceps brachii and rotator cuff muscles) between the head of humerus and the space formed between the acromion process of the scapular and the coracoacromial ligaments (McCann & Bigliani 1994). The fraying commonly seen on the undersurface of the supraspinatus tendon in arthroscopic observation and cadavaric studies is ascribed to impingement rather than to tensile overload (Blevins 1997).

The progression of the condition as described by Neer (1983) and elaborated in Lehman (1988) and Ticker et al. (1996) is as follows: Stage 1 impingement: characterised by oedema and haemorrhage in the subocromial bursa and tendon (which typically causes pain after activities and is usually seen in athletes aged 12-25 years) ➔ Stage 2: thickening and fibrosis of the subacromial bursa and tendinitis (which typically causes pain during activities but may cause pain at night, usually seen in athletes 25 years of age or older) ➔ Stage 3: subsequent partial or full thickness tears of the rotator cuff tendons and bone spurring (commonly seen in athletes 40 years of age or older). Athletes, such as tennis players, that repeatedly perform overhand motions may pass through the stages of the condition more rapidly than indicated above and onset may be earlier (Ticker et al. 1996).

The condition is characterised by inflammation and intense pain especially if the affected arm is lifted vigorously forward and upward (the positive impingement sign). Pain at night and pain in activities of daily living that require the use of the hand at shoulder level and above are also characteristic complaints (Mc Cann & Bigliani 1994).

Glenohumeral instability

The glenohumeral ligaments are the primary static stabilisers of the shoulder resisting anterior translation of the humeral head. They are grouped into three distinct segments: the superior, middle and inferior ligaments. These ligaments are repeatedly placed under considerable stress in the overhead athlete. The chronic repetitive stresses to the glenohumeral ligaments slowly elongate capsular restraints and cause glenohumeral instability, usually anterior. This results in secondary mechanical impingement and tensile overload. The concept of an instability continuum has been developed to explain the progression of shoulder dysfunction in younger athletes (approximately 18-35 years) who are most commonly involved in sports such as swimming, tennis, baseball or javelin throwing. The stages are as follows: instability caused by weakening of the anterior wall muscles through repeated stress➔anterior subluxation of the humeral head➔impingement➔rotator cuff tear (Jobe & Pink 1993).

Other conditions

Priest et al. (1988) postulate an association between shoulder symptoms in tennis players, particularly elite players, and a condition known as ‘tennis shoulder’. The name ‘tennis shoulder’ is given to a characteristic postural change — a droop of the excessively exercised shoulder — most apparent in elite tennis players but also seen in recreational tennis players, other athletes and workers. The authors reported that 50% of 84 highly skilled long-time players enrolled in a research study of tennis elbow were also found to have a downward depression of the dominant shoulder. They suggested that the shoulder deformity was caused by one-sided training which increases the mass of the playing arm depressing the shoulder by gravitational pull, and the overhand service motion which repeatedly stretches the shoulder elevating muscles until they eventually allow the shoulder to droop. They reported that more than 50% of players in the study also suffered shoulder symptoms (mostly anterior rotator cuff symptoms) at some time in their careers. The authors implied (but did not test) an association between shoulder depression and shoulder impingement, irritation of the rotator cuff and, in extreme cases, thoracic outlet syndrome.

Other rarer conditions causing shoulder pain include cervical radiculopathy, calcific tendinitis and degenerative joint disease of the acromiaclavical joint (McCann & Bigliani 1994).

Pathophysiology

The mechanisms of the serve, overhead smash and high forehand or backhand volleys in tennis require shoulder rotation, abduction and elevation often at the limits of range of motion which places great demands on the shoulder (Bigliani et al. 1992; Plancher et al. 1995). The most important anatomical structures relevant to shoulder pain in tennis players are the rotator cuff muscles, which provide dynamic stability of the glenohumeral joint and the glenohumeral ligaments, which provide static stability (McCann & Bigliani 1994).

The four muscles of the rotator cuff immediately surround the anterior, superior and posterior aspects of the glenohumeral joint and their tendons (subscapularis, supraspinatus and infraspinatus) form a cuff or hood about the humeral head. When the muscles act individually they assist to move the humerus, when all four muscles contract together, they keep the humeral head centred in the glenoid by exerting a compressive force which prevents upward displacement of the humeral head on the glenoid. If the muscles function become impaired, superior translation of the humeral head occurs resulting in impingement of the cuff under the coraco-acomial arch (Blevins 1992). In a well-conditioned athlete with good stroke mechanics the cuff performs its function successfully but if demands on the cuff are increased beyond its capability, injury results.

Prevention, treatment and rehabilitation

Prevention

Kibler et al. (1996) reviewed the literature on shoulder pain and reported that tennis players had been shown to have developed decreased internal shoulder rotation when compared with standard findings, their non-dominant side and with players from other sports. The authors indicated that these adaptations are considered important to both injury risk and rehabilitation.

Kibler and his colleagues subsequently studied glenohumeral rotational range of motion in 39 members of the United States Tennis Association National Tennis Team and touring professional program. The study documents a statistically significant loss of internal rotation in the shoulders of players. The loss was progressive with age and years of tournament played. They indicated that early detection and a corrective training program should be considered, as adaptations may result in deleterious biomechanics affecting both performance and risk of injury.

It has been suggested that proper technique, body conditioning, strength and flexibility as well as a gradual increase in the level of tennis play and a balanced pre-season program will help to prevent and control shoulder injuries (McCann & Bigliani 1994; Ellenbecker 1995).

Chandler et al. (1992) recommended strength training as a result of their investigation of 24 college players tested for bilateral shoulder internal/external rotation strength. Their data indicated that tennis imposes adaptive strength changes in the dominant arm. Primarily, these changes occur by increasing the strength of the internal rotator muscle groups without subsequent strengthening of the external rotator muscle groups. The inability of the external rotators to handle the force loads created in a repetitive internal rotation movement, such as the tennis serve, may predispose the athlete to shoulder injury, as the rotator muscle groups cannot decelerate the arm. They concluded that specific exercises to strengthen the shoulder in external rotation will help maintain rotation strength balance and may prevent or lessen the severity or repetitive overload injuries.

Conservative treatment

In tennis players and other athletes the symptoms of primary impingement syndrome and glenohumeral instability may overlap and make diagnosis difficult so a classification scheme consisting of four groups was developed by Jobe and Pink (1990). Group I encompasses patients, mainly older recreational athletes, with pure and isolated impingement and no instability. Group II patients, frequently young overhead athletes, demonstrate primary instability from anterior ligament and/or labral injury with impingement secondary to the microtrauma that comes from overuse. Group III patients, also commonly young overhead athletes, demonstrate generalised ligamentous laxity and shoulder instability and secondary impingement. Group IV patients, rarely tennis players, have usually experienced a traumatic event (fall or collision) which yields the shoulder unstable but without impingement.

Clinical examination and a range of diagnostic tests (radiographs, arthrography, ultrasonography, and magnetic resonance imaging) are used to classify patients and different treatment regimes are recommended for each group (McCann & Bigliani 1994; Ticker et al. 1996). The evaluation of the shoulder should include a thorough at the cervical and thoracic spine, for restrictions in the spinal area are frequently associated with shoulder problems. Evaluation of the whole player is also important, for tightness in the lumbar spine, for example, may be affecting tennis service technique and therefore contributing to shoulder pathology (private communication, Kathy Martin, Sports Medicine Consultant, Tennis Australia).

An important diagnostic test for impingement is the relief of shoulder pain by a subacromial injection of lidocaine (lignocaine) which effectively excludes other pathological conditions that cause shoulder symptoms (McCann & Bigliani, 1994). The vast majority of Group I patients (with primary impingement) are held to gain relief from a non-surgical approach which includes: modification of activity (rest from the tennis strokes and other activities that cause pain); non-steroidal anti-inflammatory drugs (NSAIDS-lidocaine); one or two injections of corticoidsteroid if symptoms persist; and, most importantly, a supervised intensive rehabilitation program. Physical therapy is used to address minor limitations in flexibility at the extremes of motion, especially internal rotation, and to strengthen the rotator cuff and parascapular muscles (McCann & Bigliani, 1994; Lehman 1988; Ticker et al. 1996). As for 'tennis elbow' the condition usually responds to rest.

The recent Cochrane Collaboration review of interventions for shoulder pain (http://hiru.mcmaster.ca/cochrane/cochrane/revabstr/ab001156.htm) concluded that there was little evidence to support or refute the efficacy of common interventions (drug treatments, physiotherapy, manipulation under anaethesia, hydrodilation, or surgery) and that there was a need for further well-designed clinical trials and research to establish uniform definitions and valid and reliable outcome measures. The only positive finding was that subacromial steroid injection showed a benefit over placebo for improving range of abduction in patients with rotator cuff tendonitis when results from three trials were pooled (95% CI 14 to 55).

Surgery

Ticker et al. (1996) outline the operative interventions for the different classifications of shoulder injury. Operative intervention (an anterior acromioplasty, coracoacromial ligament resection and bursectomy) is considered for Group I patients with persisting symptoms and deficits in shoulder function (after 6 months quality treatment and rehabilitation) or with rotator cuff tear/s, which are usually found in older athletes. Small tears may be repaired arthroscopically or a mini-open operation which preserve the deltoid muscle, larger tears require open subocromial decompression and rotator cuff repair which involves incisement and repair of the deltoid (Ticker et al. 1996).

For athletes who present with primary instability (Group II and Group III) the initial treatment is rehabilitation of the rotator cuff. If this fails an anatomical repair to restore stability and function to the glenohumeral joint is indicated. For Group II this involves repairing the anterior ligament and labrum; for Group III an open repair to decrease the volume of the capsule of the glenohumeral joint is indicated. Athletes in Group IV, with pure instability usually from macrotrauma, are less likely to respond to a rotator cuff rehabilitation regime and operative repair to tighten the shoulder capsule is usually required (Ticker et al. 1996).

Bigiliani et al. (1992) noted that a number of studies have reported excellent pain relief and return of function in the general population from operative treatment of rotator cuff tears (80-90% success rate). However, they found that there was no knowledge about whether surgery is effective for tennis players who have frank tears of the rotator cuff (usually older players). Consequently, the authors investigated the effectiveness of surgery (anterior acromioplasty and rotator cuff repair) in 23 tennis players with a symptomatic full thickness rotator cuff tear who wished to return to tennis play. Their average age was 52 years and the average follow-up time was 42 months.

Nineteen patients (83%) achieved a good result, were pain free and were able to return to tennis play at their pre-symptomatic level. Three patients (13%) with massive tears had a satisfactory result and were able to play tennis at a lower competitive level. One patient with a massive tear had an unsatisfactory result. The high success rate was attributed to the high motivation of most of the group who adhered to a prolonged and intensive rehabilitation program over a 12-month period, and aspects of the operative technique (McCann & Bigliani 1994). A lower rate of return to former level of competitive play after surgery for tears in the rotator cuff (56%) was reported for a younger group of athletes by Tibone et al. (1986). However, most were college and professional baseball pitchers who face comparatively greater demands on the shoulder than club or regional level tennis players. Three of the four tennis players (average age 39 years) in the series had partial thickness tears and all three were able to return to their prior level of competition.

Rehabilitation

For optimal results after surgery, an intensive and tailored rehabilitation program over several months is recommended. The recommended program consists of early protected range of motion exercises, followed by a regimen of more aggressive strengthening and stretching exercises until near full range of motion and strength is achieved, which allows a graded return to full tennis play (McCann & Bigliani 1994).

6.2 LOWER EXTREMITY INJURY

Tennis places great demands on the legs. The ‘sprint, stop and cut’ nature of running in tennis puts repetitive demands on the bones, musculo-tendonous and ligamentous structures of the lower limbs. The predominance of lower limb injuries over upper limb and central body injuries in tennis has been consistently noted in a number of studies, particularly those involving elite junior players (Table 8). The exception is the study of 109 Danish elite players by Winge et al. (1989) which found that upper extremity injuries (46%) were more frequent than lower extremity (39%) and back injuries (11%) which suggests that the pattern of injury may be different for adult professional players but requires confirmation. The comparative incidence of lower limb to upper limb injury in recreational players has not been reported.

Table 8: Reported frequency of lower limb injuries compared to upper limb and trunk injuries among tennis players

Population	Age	Sample size	Proportion (%)	Reference
Elite juniors (Australian Institute of Sport tennis scholarship holders)	16-20	45	Lower limb: 59% Upper limb: 20% Trunk (inc. back): 21%	Reece et al. 1986
Elite juniors (International and US)	11-14	97	Lower limb: 54% Upper limb: 35% Trunk (inc. back): 11%	Kibler et al. 1988
Elite juniors (USTA championships)	14-17	1440	Lower limb: 49% Upper limb: 27% Back: 21%	Hutchinson et al. 1995
Sports injury clinic presentations	-	131	Lower limb: 45% Upper limb: 35% Trunk (inc. back): 20%	Chard & Lachmann 1987.
Danish elite professionals	14-48	104	Lower limb: 39% Upper limb: 46% Back: 15%	Winge et al. 1989

The ankle (including Achilles tendon), foot, knee and thigh (hamstring) are consistently reported as the sites of most lower limb injury in elite junior players (Reece et al. 1986; Kibler 1988; Hutchinson et al. 1995). Reilly and Collier (1994) provided only limited information on the pattern of lower limb injury among young recreational tennis players. Their retrospective survey of 100 young English club level players found that the knee was the highest ranking site of injury (ahead of the dominant elbow and shoulder) and accounted for 20% of all injuries reported by players for the previous 12 months. No information was given on the frequency of other lower limb injuries in this group.

The available evidence (which is not comprehensive) suggests that knee and ankle injuries are the most prominent lower limb injuries among adult tennis players. Winge et al. (1989) reported that the ankle, foot and knee contributed most of the lower limb injuries in the study of Danish elite professionals (Winge et al. 1989). Knee and ankle injuries were the highest-ranking lower limb injuries reported from both a survey of 260 Western Australian recreational tennis players conducted by Kamien (1989) and a retrospective study of sports injury clinic presentations over an 8-year period conducted by Chard and Lachman (1987).

Tennis-related injuries to the lower limb may be chronic or acute in nature. Chronic injuries are caused by repetitive stresses (microtrauma) to the musculo-tendonous structures and include muscle strain, stress fractures, tendinitis and tendon ruptures. Acute injuries are also common and include ankle sprains, muscle cramps, ruptures of the Achilles tendon and tearing of the medial head of the gastrocnemius (calf muscle), which has been given the eponym ‘tennis leg” (Zecker & Leach 1995).

6.2.1 Ankle and foot injury

Ankle injury

Ankle injuries, mostly inversions resulting in damage to the lateral ligaments, are the most common injury in sports participants in general (Zecker & Leach 1995; Hume & Gerrard 1998). There are no large-scale prospective studies of ankle injury among recreational or elite tennis players in the literature. However, the available evidence suggests that ankle injuries account for a sizeable proportion of all injuries in elite tennis but may be less prominent among recreational tennis players.

Studies of elite junior players report that ankle injuries accounted for 11% of all injuries (new and recurrent) in the 6-year study of injury occurring in 1,440 participants in the USTA Boy’s Tennis Championships (Hutchinson et al. 1995); 20% of injuries recorded among 97 US and international elite juniors in a retrospective study covering an 18-month period by Kibler et al. (1988); and 15% of injuries to elite young Australian tennis players in a retrospective review of injury to 45 players over a 4-year period by Reece et al. (1986). The latter study was the only one of the three to report the nature of ankle injury in any detail. Eighty-eight percent of the ankle injury cases were sprains and 8% were tendinitis/tenosynovitis.

Winge et al.(1989) reported that ankle injuries (83% sprains, 17% Achilles tendon overuse injury) accounted for 13% of the 46 injuries recorded prospectively over one season in a randomly selected sample of 89 adult elite Danish tennis players.

Limited evidence on the frequency of ankle injuries among recreational players is provided by two studies – a survey of case records in one sports clinic by Chard and Lachmann (1987) and a survey of club-level tennis players by Kamien (1988). Chard and Lachman (1987) conducted a retrospective survey of injury associated with racquet sports treated at one English sports injury clinic. They found that ankle sprains accounted for 5% of the tennis injury cases treated over an 8-year period (the proportion of ankle overuse injuries was not mentioned) and that ankle injuries were rarer in tennis than in squash (12%) and badminton (10%).

The incidence of ankle injury among recreational players (mostly adults) was reported from a retrospective survey of 260 Western Australian recreational club players conducted by Kamien (1988). He found that 5% of players self-reported that they had sustained an ankle injury (that prevented tennis playing for longer than one week) in the previous twelve months. In this study, the knee (9%), shoulder (7%) and back (5%) ranked higher than the ankle in terms of injury frequency. By contrast, the Victorian emergency department presentations data showed higher frequencies of ankle sprains/strains for adults and children. Ankle sprains/strains accounted for 9% of child injuries and 18% of adult injuries that occurred in formal recreational tennis.

Ankle sprains

The ankle is put at high risk of sprains, mostly inversions, in tennis due to the footwork required in stroke play and the quick starts, stops and changes of direction in a confined space which characterise the game. Instability of the ankle joint complex may predispose a player to inversion injury. Ankle sprains tend to occur at foot strike during running or when a player is landing from a jump (Hume & Gerrard 1998; Robbins & Waked 1998). Robbins and Waked (1998) note that ankle sprains are uncommon in barefoot athletes and theorise that most ankle sprains are caused by footwear. They believe that footwear impairs human judgement of the position and orientation of the plantar surface of the foot, causing inappropriate positioning of the foot in space before contact with a surface.

Most ankle sprains in tennis are first degree and respond to RICE treatment – rest, ice, compression and elevation – and light resistive exercise. Some support (taping or bracing) may be recommended for 6-12 weeks on return to tennis play. If ligament damage is extensive then reconstructive surgery may be required. A detailed discussion of the efficacy of taping and bracing in the prevention of ankle ligament injuries and re-injuries is in section 8.8.2.

Achilles tendon rupture

A less common acute injury is a rupture of the Achilles tendon that usually occurs when a player lands on his toes as the knee extends (Zecher & Leach 1995). High-risk movements in tennis include the first step forward after a serve and during ground strokes as forward and side lunges are made. The player suddenly feels a pop behind the ankle joint but can usually walk flat-footed. Zecker and Leach (1995) note that there is controversy in the literature on the risks and benefits of operative versus non-operative treatment for Achilles tendon rupture. The authors believe that operative treatment promises the best outcome for young, competitive tennis players who want to return to their previous level of play and non-operative treatment may be more suitable for older athletes who are engaged in low-demand sporting activities.

Achilles tendinitis

The more common Achilles tendon injury is tendinitis/tendinosis (chronic ankle pain indicating Achilles tendon damage, tenosynovitis or retrocalcaneal bursitis). The treatment regime is as recommended for elbow and shoulder tendinitis/tendonosis: rest; ice to reduce inflammation; nonsteroidal anti-inflammatory drugs (NSAIDs); controlled stretching and strengthening of surrounding muscles; the use of orthotics if a biomechanical assessment shows that excessive pronation is present; an injection of steroids if injury is recalcitrant; and surgery if pain persists after at least 6 months or more of quality conservative treatment (Zecher & Leach 1995). The lack of research evidence to support the effectiveness of treatment with NSAIDs and steroids, as explained in the section on 'tennis elbow', also applies to the treatment of chronic Achilles tendonitis/tendonosis. Frequently, the addition of orthotics combined with conservative treatment will eliminate the problem (private communication, Kathy Martin, Sports Medicine Consultant, Tennis Australia).

Foot injuries

Foot injuries in tennis include plantar fasciitis (an overload injury of the plantar fascia from stresses on the balls of the feet which causes pain at the medial tubercle where the plantar fascia attaches); posterior tibialis tendinitis; degenerative arthritis of the great toe; 'tennis toe' (bleeding under the nails of the toe caused by toes being jammed against the shoe box); and corns and calluses (Leach 1988; Zecher & Leach 1995). The overload conditions (plantar fasciitis and posterior tibialis tendinitis) generally respond to conservative treatment (rest, ice, anti-inflammatory medication), an appropriate program of controlled stretching and strengthening and correction of functional or biomechanical foot abnormalities (Leach 1988; Zecher & Leach 1995).

Correction of major foot faults may be effected by a change to more supportive athletic footwear, support for the midportion of the foot (for plantar fasciitis) and orthoses to correct pronation if appropriate (Leach 1988; Zecher & Leach 1995). The quality of evidence on the injury prevention effects of orthoses is discussed in more detail in section 8.4.3. 'Tennis toe' can be prevented by keeping the toenails short and wearing shoes with an adequate toe box (Zecher & Leach 1995). Because of the dominance of footwork in tennis, it is important that players at all levels wear well-fitting good quality tennis footwear and seek medical advice early if foot pain develops.

6.2.2 Calf injury ('Tennis leg')

'Tennis leg' is a strain of the gastrocnemius muscle in the calf which is experienced by the athlete as a sharp or burning pain at the juncture of the upper third and lower two thirds of the posterior calf muscles (Gecha & Torg 1988; Leach et al. 1988). The mechanism of injury appears to a sudden ankle dorsiflexion in the affected leg, where the knee has been previously extended and the ankle plantar flexed, as commonly encountered in the back leg of a tennis player during follow-through of a serve (Gecha & Torg 1988). The injury is most commonly seen in younger male tennis players (Gecha & Torg 1988).

Some players report short, stabbing painful episodes a few days prior to injury and as this prodrome tends to occur early in the season it is thought that lack of pre-season conditioning may play a role in this injury, along with lack of proper warm-up (Gecha & Torg). This acute injury is reported to respond well to aggressive treatment involving immediate Ace wrapping, the application of ice packs, the initial use of crutches for the first week after 24 hours of complete rest, anti-inflammatory medication, and the immediate institution of a progressive passive then active stretching and strengthening exercise program for both legs (Gecha & Torg 1988). A heel lift is recommended, to take the strain off and protect the affected muscle, but it is recommended that it not be used for too long or musculotendinous shortening may occur (Gecha & Torg 1988).

6.2.3 Knee injury

Knee problems appear to be relatively common in tennis players as the game places great stresses on the knee. However, no large-scale prospective studies have been conducted on knee injury among recreational or elite tennis players, so accurate and detailed information on the incidence, patterns and types of knee injury among tennis players is not available.

Frequency

The proportion of knee injuries, relative to other tennis injuries, reported from studies of elite young athletes shows considerable variation. Among young, elite athletes knee injuries accounted for:

- 6% of all injuries (new and recurrent) in the study involving 1,440 players competing in the USTA Boy's Tennis Championships over a 6-year period (Hutchinson et al. 1995);

- 11.2% of injuries to elite young Australian tennis players in a retrospective review of injuries in 45 Australian Institute of Sport tennis scholarship holders over a 4-year period by Reece et al. (1986); and

- 18.8% of injuries recorded among 97 US and international elite juniors in a retrospective study covering an 18-month period by Kibler et al. (1988).

The only study to provide any information on the specific types of knee injury that occurred among young elite players was the small prospective study by Reece et al. (1986). The most common knee injuries in this group of young, elite players were patellar-femoral pain syndrome (42% of knee injuries) and patellar tendinitis/tenosynovitis (20%). Other less common knee injuries included Osgood Schlatter's disease, lateral meniscus injury, infrapatellar bursitis, popliteus tendinitis, bipartite patellar and anteromeniscofemoral ligament sprain.

Winge et al. (1989) reported that knee injuries accounted for 7% of the 46 recorded injuries in their prospective study of 89 randomly chosen adult, elite Danish tennis players (injuries were recorded over one season). Knee injury was the leading cause of tennis injury that prevented playing for longer than one week in the survey of 260 recreational club-level players by Kamien (1988). In this group knee injuries accounted for 9% of self-reported injuries that occurred in the previous twelve-months. The knee was also the highest-ranked site of tennis injury treated at one English sports injury clinic. Chard and Lachmannn (1987) found that knee injuries accounted for 19% of the injuries to 131 tennis players (mostly adults) treated over an 8-year period. Patellar-femoral pain (44%) and patellar dislocation (16%) were the most common knee injuries (and these kinds of knee injuries occurred more often in tennis than in squash and badminton). Other tennis-related knee injuries included collateral ligament, meninscal injury and traumatic synovitis.

Common knee injuries

Two of the more common knee injuries reported in tennis players are patellar tendinitis/quadriceps tendinitis ('jumper's knee) and patellar pain syndrome which has numerous aetiologies (Gecha & Torg 1988).

'Jumper's knee' (patellar tendinitis) is an overuse syndrome, found commonly in young athletes involved in repetitive jumping activities, that is characterised by lesions (microtears) in the patellar tendon with chronic inflammation which may progress to complete rupture (Gecha & Torg 1988). In addition to overuse and fatigue, these lesions have been associated with tall individuals, hard playing surfaces and in athletes with a quadriceps extensor mechanism abnormality (Gecha & Torg 1988).

The usual symptoms of patellar tendinitis are pain with jumping and landing after smashes, dull aching pain after sports activities which progresses to constant pain during activity and at rest in chronic cases, and point tenderness at the site of the damage (Gecha & Torg 1988; Renstrom 1995). The condition is usually self-limiting and responds to conservative treatment. The general treatment regime is that recommended for other forms of tendinitis and includes rehabilitative exercise (quadriceps isometric straight leg raising) after activity modification (avoidance of jumping activities or decreasing practice time by 50%) or complete rest as required (Gecha & Torg 1988). Surgery (the excisement of granulated tendon tissue) may be needed for chronic cases that fail to respond to conservative treatment. Return to play after surgery is, on average, 4-6 months post-operation (Renstrom 1995)

The main causes of patellar-femoral pain syndrome - a common injury in sports that demand up and down and side-to-side movements that involve 'pushing off' with the knee - are abnormalities in the function of the knee extensor mechanism (Gecha & Torg 1988). These have been classified into three main groupings: patellofemoral bony cartilaginous configuration, patellar soft-tissue support abnormalities and lower extremity malalignment (Gecha & Torg 1988). The syndrome appears to be more common in younger athletes.

The symptoms and diagnostic tests for knee overuse injuries are described in detail by Gecha and Torg (1988). Symptoms include dull aching pain in the knee after activity that is difficult to localise, progressing to pain during activity and, finally, pain throughout the day in chronic cases. Players may also report pain when negotiating stairs, when sitting in one position for extended periods, a catching or grinding sensation with motion and an associated feeling of buckling. The authors warn that patellar dislocation cases need to be separated from other sub-groups of patellar-femoral pain syndrome before progression to a common treatment regime.

The recommended treatment consists of: activity modification; ice; nonsteroidal anti-inflammatory agents; Neoprene sleeve for support; foot orthosis if required; hamstring stretching exercises and patellar mobilisation and a strengthening exercise program (Gecha & Torg 1988). Strengthening exercises include quad sets, straight leg raises, work on pelvic stabilisation and specific muscle activity for vastus medialis and glutus medius, in functional closed kinetic chain sequences (private communication, Kathy Martin, Sports Medicine Consultant, Tennis Australia). Gecha and Torg (1988) report that 80-90% of adolescent tennis players respond to conservative treatment and only in rare cases do they resort to operative procedures such as a lateral retinacular release or a more extensive proximal and/or distal patellar re-alignment. For most cases of patellar dislocation the authors advocate immobilisation of the knee in extension for a period of 4-6 weeks followed by an intensive exercise regime, rather than recourse to immediate surgery.

Tennis players also occasionally encounter meninscal problems, bursitis, osteochondritus dissecans (loose fragments in the knee joint), synovial plica syndrome and Osgood-Schlatter's Disease (pain located at the insertion site for patellar ligament into the tibia) (Renstrom 1995; Gecha & Torg 1988).

6.2.4 Other lower limb injuries

Players can also suffer from unpredictable muscle cramps that can hinder participation in competition. These painful involuntary muscle contractions occur most frequently in the hamstring, then the calf muscle (gastrocenemius) and eventually all muscles of the lower extremity (Leach 1988; Zecher & Leach 1995). The exact physiological cause of cramps is unknown but they appear to be associated with muscle fatigue and dehydration and, perhaps, electrolyte imbalance and the 'tension' of playing in a competitive situation (Leach 1988; Zecher & Leach 1995). Suggested preventive measures include: adequate hydration before and during the match, especially in hot and humid weather; a diet high in carbohydrates with adequate amounts of potassium and sodium; proper warm-ups and stretching and adequate conditioning for muscle endurance and strength (Leach 1988; Zecher & Leach 1995). Quinine sulphate tablets, taken at bedtime have been found to be helpful in some chronic cases. These measures have not been formally evaluated.

6.2.5 Factors associated with lower limb injury

Fricker et al. (1986) attributed the predominance of injuries to the lower limb in the group of tennis players he studied at the Australian Institute of Sport (AIS) to the hard plexipave surface on which the athletes trained, inadequate footwear (which did not provide adequate support to both the feet and ankles) and lack of training and conditioning of the lower extremities. These observations were supported by Nigg et al. (1986), who also indicated that the length of the game and individual movement pattern could influence the occurrence of lower limb injuries. Renstrom (1995) included extrinsic factors such as training errors, improper shoes and 'unforgiving' all weather playing surfaces (asphalt base and concrete) and unsuitable environmental conditions as well as intrinsic factors such as malalignment and muscle imbalance as possible contributors to lower limb injuries.

These observations are speculative; there have been no prospective studies of risk factors for lower limb injuries in tennis. Barker et al. (1997) recently reviewed the risk factors for ankle injuries (mostly sprains) covering published prospective studies in all sports. The authors concluded that there was some agreement in the literature that orthosis (bracing) reduced the risk of ankle injury in players with previous sprain and that there was no correlation between foot type (pronated, supinated or neutral) or generalised joint laxity and increased ankle sprain. In terms of the other proposed risk factors that had been studied (shoe type, intensity of play, player position for team sports, previous sprain, foot size, ankle instability, lower extremity strength and dominance) the available evidence was either weak or controversial. The authors called for an extension of current research effort in the form of prospective, controlled studies that meticulously collect exposure data and report all data collected to allow accurate comparison between studies and continued analysis.

6.3 BACK AND TRUNK INJURY

Available evidence suggests that a substantial proportion of tennis-related injuries are sited at the low back or trunk (Kibler & Chandler 1994, Hainline 1995). The back, trunk and hips are important as they act as a centre of rotation and are a link that transfers the large forces generated in the legs to the shoulder and arm (Kibler & Chandler 1994).

6.3.1 Back injury

The epidemiology of back injury in high level and recreational tennis players is not well studied, there are no prospective longitudinal studies that specifically address the issue of back pain/injury in tennis players. The available evidence suggests that back pain is relatively common, especially among elite players. The pathophysiology of low back injuries is also not well understood. Marks et al. (1988) identified common low back injuries in tennis to include include lumbar strain, lumbar disc degeneration/herniation (caused by repetitive microtrauma or an acute tear), facet impingement syndrome/arthropathy and piriformis syndrome. Acute lumbar strain (including ligament strain) is probably the most common of these injuries. According to the authors lumbar strain may be over-diagnosed and lumbar disc disease under-diagnosed because acute low back pain is often attributed to strain when it is caused by an acute tear in the annular fibrosis of the lumbar disc.

Frequency and types of back injury

Marks et al. (1988) quote an unpublished survey which found that 38% of 143 tennis players on the US Men's Professional Tennis Tour had missed at least one tournament as a result of low back pain. Forty-three percent of the surveyed players reported chronic low back pain and 11 (29%) of the 38 players who sustained acute injuries during competition suffered injuries to the lumbosacral spine.

Hainline (1995) observed that 18 (10%) of the 174 players who were evaluated medically at the US Open Tennis Championships in 1992 and 1993 had low back complaints, 72% of which were diagnosed as lumbar strain. Other less common injuries were degenerative disc disease and suspected lumbar disc herniation. He reported that none of the 18 injured players had regularly engaged in any conditioning program to improve the strength and flexibility of the back. Sward et al. (1990) studied 30 elite tennis players aged between 17 and 25 years. All were selected at random without prior knowledge of previous or present back injuries or symptoms. Fifteen players (50%) reported a history of thoracic-lumbar back pain of at least one week's duration; nine players (30%) reported moderate back pain, and six players (20%) had severe back pain. Fourteen players (47%) had radiographic abnormalities of the thoracic lumbar spine but these changes did not correlate with a history of back pain.

Back injuries also appear to be a problem among junior high-level players. Hutchinson et al. (1993) report that back injuries (described as mostly low back sprains and strains) were 'surprisingly common' among players at the annual USTA Boys Championships accounting for 16% of all injuries over the 6-year surveillance period. Reece et al. (1988) found a similar proportion of back injuries (10%, mostly low back/back pain complaints) among the 45 elite Australian Institute of Sport tennis players (aged 16-20 years) they followed up over a four-year period. Also, Kibler et al. (1988) reported that 9% of 97 US junior competitive tennis players in their survey had a history of back injuries.

Kamien (1989) reported that 9% of 260 club level players in Western Australia (aged 10 to 60+ years) had suffered a back injury, that prevented tennis play for longer than one week, in the previous 12 months. The only other information on the relative frequency of back injury compared to other injuries in non-elite tennis players is supplied by Chard and Lachmann (1987) who conducted an 8-year retrospective study on racquet sports injuries presenting to one English sports injury clinic. Approximately 16% of injuries to the 131 tennis players presenting to the clinic were to the back, 43% of which were clinically due to lumbar disc prolapse.

Aetiology

Tennis involves a number of strokes that may place the back at risk. Biomechanical models have shown that the strokes that impart the greatest stress on the lower back are the serve and overhead shot because they combine hyperextention and rotation (Marks et al. 1988; Hainline 1995). In the serve, the lumbar spine hyperextends and rotates with the hitting arm away from the net during the toss. The trunk then powerfully laterally flexes, and the shoulders and trunk rotate toward the net as forward trunk flexion occurs causing stresses on the back. The volley, forehand and backhand groundstrokes, singly and in combination, place the back at risk of injury because they involve a marked degree of rapid axial rotations to right and left (Marks et al. 1988). It is the rotatory motion that increases the likelihood of disc injury and muscle strain. According to Marks and his colleagues, variations to 'textbook' stroke mechanics may increase or decrease the risk of each pathological back condition.

Physiological adaptations to the trunk, which predispose a player to back injury, are also reported to occur in tennis players. These adaptations are caused by the asymmetric loading of the dominant shoulder and the non-dominant side of the trunk when strokes are initiated (Sward et al. 1990). The quick, repetitive nature of the sport can also cause fatigue in the supporting structures of the back creating overuse injury (Hainline 1995).

Treatment and rehabilitation

There are no controlled studies to guide the rehabilitation of low back injury in tennis players (Hainline 1995). It is generally recommended, on the basis of clinical and anecdotal data, that the initial treatment in all cases should include pain control and rest, followed by gradual physical rehabilitation (Hainline 1995; Marks et al. 1988). It is also recommended by Hainline (1995) that initial bed rest should be kept to a minimum, except for cases of acute lumbar disc herniation. Hainline based this advice on findings from a randomised clinical trial conducted by Deyo et al. (1996). Deyo and colleagues reported significantly fewer days off work (p=0.01) and no differences in other functional, physiological or perceived outcomes at three-months follow-up in the group of 'walk-in' patients with mechanical low back pain who were prescribed two days of bed rest compared to their counterparts prescribed 7 days of bed rest.

Once pain is manageable, patients are advised to include walking into a daily graduated schedule of flexion, extension, isometric and lumbar stabilisation exercises, and to consult a coach to modify strokes that place the lumbar disc at risk of shearing injury (Hainline 1995; Marks et al. 1988). Other treatment modalities (ultrasound, massage, manipulation, NSAIDs, and corticosteroids) are used by clinicians for specific back pathologies. Except for manipulation, their effectiveness has not been verified by clinical trials (Hainline 1995). It is also recommended that all tennis players incorporate back strengthening and flexibility exercises in their preparation and warm-up program to redress any imbalances caused by repetitive back flexion and rotation in tennis play (Marks et al. 1988).

6.3.2 Other trunk injuries

Abdominal injuries in tennis are usually acute muscle strains (usually affecting the rectus abdomnis and to a lesser extent the obliques) caused by stretches to make the overhead tennis stroke, although lumbar spine stiffness, pelvic girdle mal-alignments and instabilities may also be causative factors (Balduini 1988; personal communication, Kathy Martin, Sports Medicine Consultant, Tennis Australia). Acute groin strains also occur, usually when the player is attempting to halt progress by sliding or planting the leading foot (Balduini 1988). On clay surfaces sliding is the common mechanism of injury; loss of traction causes overextension which may strain or the abductors, or less commonly the iliopsoas (Balduini 1988). On synthetic surfaces the front foot when planted may 'stick', opposing the forward motion of the body causing abdominal groin muscle tears (Balduini 1988).

Most cases of abdominal and groin strains respond to one to two weeks rest from all strenuous activities, the use of ice to reduce inflammation, followed by a graduated program of stretching and strengthening exercises (low-intensity isotonic rather than isometric) (Balduini 1988). An aerobic conditioning program, including swimming and cycling, prior to progressive return to play is also recommended (Balduini 1988). At the elite level, unloading taping of the abdomen is used and frequently allows the player to continue to compete, and heal (personal communication, Kathy Martin, Sports Medicine Consultant, Tennis Australia). As previously mentioned, the effectiveness of NSAIDs for reducing inflammation and ultrasound treatment to enhance tissue healing is debatable (Labelle et al. 1992). Ultrasound should not be used in the groin region of males because of the adverse effects of heat on sperm production (Balduini 1988).

There are a number of less common causes of abdominal and groin pain in athletes – acute abdominal process, hernia, epididymitis, torsed testicle, herniated invertebral disc, osteitis pubis, stress fracture and entrapped intercostal nerve – which should be differentiated from muscle strains in the diagnostic stage (Balduini 1988).

6.4 HEAD AND NECK INJURY (INCLUDING EYE INJURY)

6.4.1 Head and neck injury

The majority of head and neck injuries in tennis are associated with direct trauma caused by the player being struck by the racquet or ball (Mohtadi & Poole 1996). These injuries are probably more frequent in informal tennis play and doubles matches. The VISS hospital E.D. data showed that 45% of informal tennis injuries were caused by a hit by the ball or racquet. The largest proportion of 'hit/struck by' cases (48%) presented with superficial injuries or open wounds. Thirty-seven percent of these injuries were to the head and face. Facial fractures, although not usually catastrophic, can result in long term morbidity and deformity and may require hospitalisation and surgery (Lim et al. 1993). There is little discussion of facial injuries and potential prevention measures in the research literature.

6.4.2 Eye injury

Sports-related eye injuries are not numerous compared to work- and home-related eye injuries, but are of concern because sports contribute a disproportionate number of severe eye injuries (Jones 1993; Fong 1995). For instance, Fong (1994) conducted a prospective cross-sectional survey of all sports-related eye injuries treated at the Royal Victorian Eye and Ear Hospital over a two-year period and identified 700 cases of sports-related eye injury, representing 5% of all eye injury cases but 22% of admissions.

Frequency

Reports on sports-related eye injury generally focus on squash and badminton because these racquet sports contribute a higher proportion of all sports eye injuries than tennis. However, specialist eye hospital case series studies consistently show that tennis ranks in the top five sports in terms of frequency of injuries, accounting for 7-11% of sports-related eye injuries (Fong 1994; Jones 1988; Gregory 1986; Larrison et al. 1990). The exception is the study by MacEwan (1987) which investigated all patients attending two eye infirmaries in England over an 18-month period and found that only 3% of 246 sports-related eye injuries were tennis injuries.

The Victorian study by Fong (1994) was the only one that adjusted frequency data for the numbers of sports participants. She compared the incidence of eye injury per 100,000 participants in the seven sports that ranked highest in terms of frequency of eye injury. Because of its popularity, tennis slipped down the ranking table falling from 5th place based on frequency data (behind squash, Australian Rules football, netball and basketball) to 7th place when incidence rates were compared.

Aetiology and prevention

These studies provide little or no detailed information on the nature of eye injuries in tennis, so are not very useful for the development of preventive measures. Two earlier case series of eye injuries in tennis players suggest that player experience does not protect against eye injury (Duke 1976 and Holter 1977 cited in Maylack 1988). In both studies the average experience of injured players was 5 years. The authors suggest that experienced players are more at risk of eye injury because they keep their eyes on the ball whereas inexperienced players watch their opponent (Duke 1976 and Holter 1977 cited in Maylack 1988).

None of the participants in the Fong (1994), Jones (1988), MacEwan (1987) and Gregory (1986) studies were wearing protective eyewear. Only 5% of the 202 patients in the Larrison et al. (1990) study were wearing protective eyewear at the time of injury. The value of protective eyewear for tennis players is discussed in section 8.5.1.

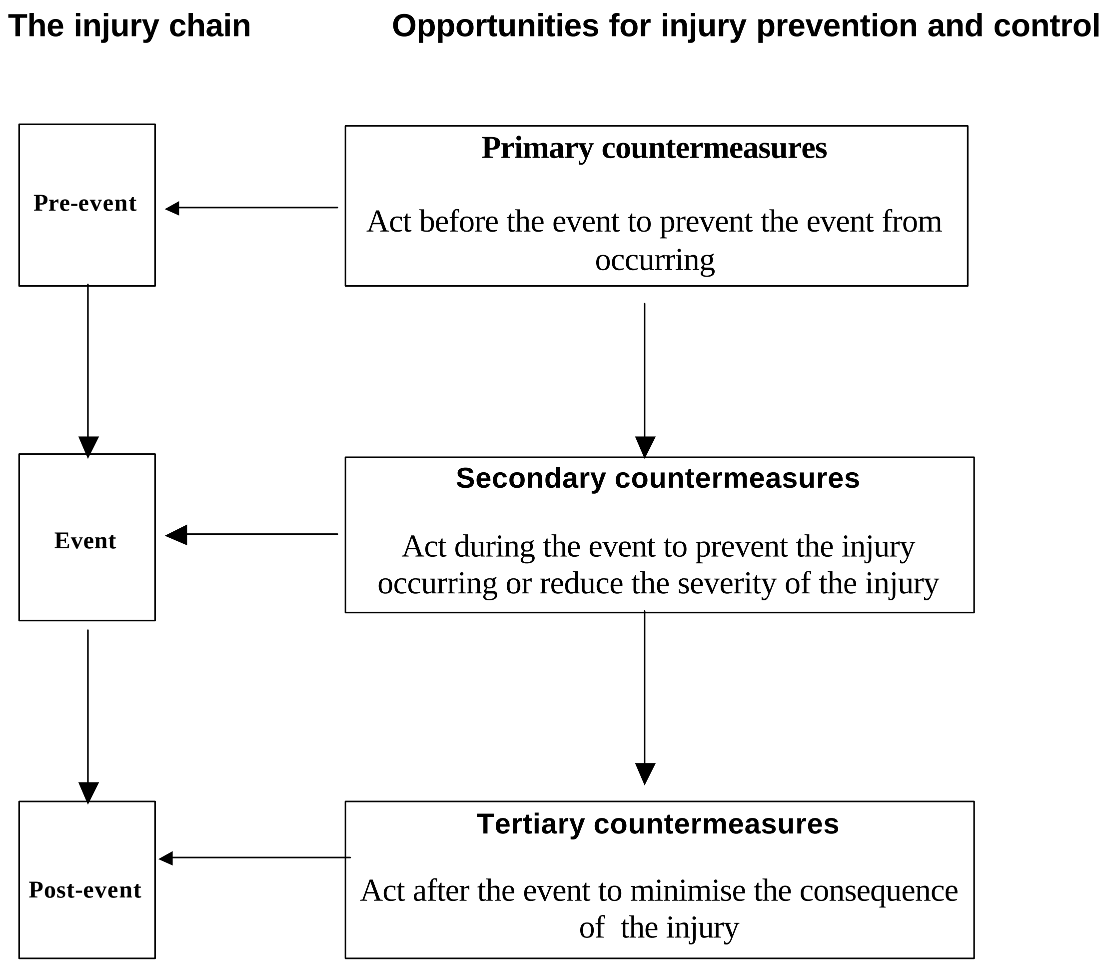
7. AN OVERVIEW OF INJURY COUNTERMEASURES

Injuries are considered to result from a culmination of a set of circumstances and pre-existing conditions that may best be understood as a chain of events: pre-event, event and post event (Robertson 1983). Injury countermeasures are measures that can "counter", that is prevent or reduce the risk of injury. A number of researchers have described how countermeasures should be targeted at the different links in the chain of events leading to injury (Haddon 1972; Ozanne-Smith & Vulcan 1990; Watt & Finch 1996).

7.1 PRIMARY, SECONDARY AND TERTIARY COUNTERMEASURES

Such injury countermeasures can be equated with primary (pre-event), secondary (event) and tertiary (post-event) prevention in the chain of events leading to an injury (Figure 2). Primary countermeasures act before an event or incident that could potentially lead to injury, to prevent the event from occurring in the first place. Secondary countermeasures act during the event, to prevent the injury occurring or to reduce severity of the injury. The third level of countermeasures act after the chain of events/incidents leading to injury and help to minimise the consequences of injury.

Figure 2: Countermeasure opportunities in the injury chain



Source: Watt & Finch (1996)

There are multitudes of factors that contribute to the risk of injury in tennis players. Generally, more than one factor is involved in each injury. Consequently, there are a number of countermeasures aimed at the primary, secondary or tertiary level that can be considered when designing injury prevention interventions (Table 9). A systematic approach is required to implementation.

Table 9: Potential countermeasures to tennis injury

Primary	Secondary	Tertiary
Lessons by accredited coach/ attention to playing technique & biomechanics	Safe playing surface	Accessible, well-stocked first aid kit
Modified rules for junior players ↑	Safe playing environment	Prompt first aid by trained personnel – rest, ice, compression, elevation, referral (RICER)
Appropriate nutrition and hydration ↑	Footwear appropriate to surface and conditions	Appropriate high quality rehabilitation and graduated return to play (when fit)
Safe playing environment ↑	Adequate water intake during game	Taping & bracing to prevent re-injury (if advised)
Pre-participation screening Pre-season conditioning Appropriate training for level of play Prophylactic taping and bracing Adequate and appropriate warm-up and cool down UV protection Good quality and appropriate equipment: - footwear (and orthoses as required) - racquets - balls		

In the next section, the literature assessing the effectiveness of the various countermeasures for the prevention of tennis injuries, listed in Table 9, is reviewed. For each countermeasure, the rationale for its use as a safety measure is presented together with a critical review of the extent to which it has been fully evaluated.

8. DETAILED REVIEW OF TENNIS INJURY COUNTERMEASURES

8.1 PLAYING TECHNIQUE

There are a variety of tennis strokes—serves, ground strokes, volleys, half volleys and lobs—all with unlimited variations in spin, angles, velocities and grip positions (Nirschl 1994). Each tennis player has his/her own playing style, based on natural and acquired habits. Although there is a lack of firm evidence that poor technique is a major causative factor in tennis injury, it is generally accepted that incorrect technique has the potential to place undue stress on the body and possibly lead to injury (Kamien 1988; Renstrom 1995; Roetart et al. 1995).

A number of early epidemiological studies linked tennis elbow to an improperly executed backhand stroke (Renstrom 1995), but, in general, these reports are based on player self-reports rather than independent observation. Priest et al. (1980, cited in Renstrom 1995) found that 40% of the 75% of players in their study with tennis elbow self-reported using a faulty backhand stroke in combination with muscle weakness. Similarly, 38% of respondents with tennis elbow in the study of local league players by Carroll (1981) reported that their stroke technique, particularly in executing the backhand or serve, caused or contributed to their tennis elbow. However, most of the players attributed the symptoms to poor timing or hitting the ball at the end of the racquet rather than the technique of the stroke itself.

Roetert et al.(1995) concluded from the available kinematic evidence that the one-handed backhand places more demands on the arm and shoulder than the two-handed backhand and may cause trauma to the elbow, especially in beginners. The one-handed backhand involves the movement and co-ordination of five body parts (hips, trunk, upper arm, forearm, hand) to swing the racquet prior to ball impact. By comparison, the two-handed backhand uses only two body parts (hips and trunk), both arms moving as one with the trunk. However, no epidemiological evidence was presented to support the proposition that there is a decreased occurrence of lateral epicondylitis in players using a two-handed backhand.

Berhang et al. (1974, cited in Kamien 1990) sought independent evidence of any association between technique and tennis elbow by ‘filming’ a small number of club level players using high-speed photography. The authors found that most players who suffered from a tennis elbow used a leading elbow on the backhand stroke. Similarly, Kelley et al. (1994) reported abnormal mechanics on the backhand stroke evident on film in 8 players with lateral epicondylitis compared with 14 players with normal upper extremities. The injured players played their backhand stroke with a ‘leading elbow’, wrist extension and an open racquet face near the time of ball impact and contacted the ball in the lower half of the strings. The only other study to attempt to provide objective evidence that faulty technique contributes to tennis elbow (by Kamien) failed to confirm these findings.

The study conducted by Kamien (1988) utilised two independent tennis coaches with international reputations to observe the forehand, backhand and service strokes of a random sample of club level players with and without tennis elbow and to predict the players with the condition (Kamien 1988). The coaches were only 55% accurate in their predictions. The author also reported from the same study that he found no association between the occurrence of lateral and medial tennis elbow and players’ self-reports on the type of forehand and backhand stroke they usually used.

Despite the lack of hard evidence of an association between technique and tennis elbow, improved or changed stroke techniques (either by self-correction or with the assistance of a coach) are generally reported as helpful in alleviating symptoms of tennis elbow or preventing the recurrence of the condition (Gruchow & Pelletier 1979; Kamien 1988; Brukner & Khan 1993; Roetart et al. 1995).

As previously discussed in section 6.3.1, the strokes that are believed to place the back at risk of injury are the serve and overhead shots because they combine hyper-extension and rotation, and the volley, forehand and backhand groundstrokes because they involve rapid rotatory motion to right and left (Marks et al. 1988; Hainline 1995). According to Marks and his colleagues, variations to 'textbook' stroke mechanics may increase or decrease the risk of each pathological back condition. The example they give concerns the serve. If the ball is tossed slightly in front of the baseline (or slightly behind) it increases (or decreases) the hyperextension necessary to strike the ball. Tossing too far to the left or right will increase the lumbar rotation needed and thereby increase the potential for disc and muscle strain problems (Marks et al.1988).

Elliott (1988) noted that a number of epidemiological studies published between 1975 and 1986 linked overhead strokes, particularly the serve, with elbow and back pain and injury (largely self-reported data from injured players on the strokes that cause them most pain). He then reviewed the kinematic and kinetic studies on each phase of the serve and concluded that the literature gave no definitive indications of the reasons for elbow and back injuries. He postulated from the available evidence that the potential for injury from the serve seems to be related to the high internal forces generated (a combination of muscle joint reaction forces) particularly where these forces are associated with poor technique and high or sudden segment accelerations. Such situations arise when the racquet moves behind the body, causing the vertebral column to hyper-extend and flex laterally. Elliot suggested that the pronation of the forearm and forces associated with the swing to the ball, the impact and the early follow through can lead to injury. He concluded that the potential for injury from the service stroke could be reduced by: placing limitations on the number of serves during practice sessions; adequate physical preparation, particularly to increase lower back strength and flexibility; and using a rhythmical service technique that does not introduce excessive forces to selected body parts.

Correction of stroke technique is a complex matter that needs to be treated on an individual basis. Correct and safe skills should be demonstrated and taught by coaches and trainers. Although repetition is regarded as "the mother of learning" in tennis, overuse injuries can be avoided by varying training routines, cross training, limiting practice length and/or frequency and, where appropriate, using mental drills or performance imaging as substitutes for repetitive performance (Weaver et al. 1996).

8.1.1 Recommendations for further research, development and implementation

- Promote techniques that maximise bio-mechanical advantage and protect from excessive forces and overuse (based on current research evidence) through coaches, trainers and sporting organisations.
- Practice sessions should comprise a balanced variety of tennis strokes and other training activities.
- Rigorous epidemiological studies are required to adequately describe limb and back injuries in tennis and to investigate potential risk factors including exposure (both to training and play), playing technique and lack of physical conditioning.
- Further research is needed to expand current knowledge on the biomechanics of tennis play and associated risk of overuse injuries and investigate the optimal type and duration of training and conditioning that maximises skill development and fitness and minimises overuse injuries.

8.2 PHYSICAL PREPARATION

Tennis requires a variety of physical attributes (speed, power, endurance, strength, and balance) and specific skills. It places acute demands on the ability of the player to move quickly in all directions, change directions often, stop and start, while maintaining the balance and control to hit the ball effectively (Chandler 1995). Therefore, participants need to meet at least minimum physical, physiological and psychological requirements to cope with the demands of play and reduce the risk of injury.

8.2.1 Pre-participation evaluation

Pre-participation evaluation (PPE) is essentially a health screening process that is believed to be beneficial to athletes (Kibler 1990; Vicenzino & Vicenzino 1995). It usually involves a general medical examination and the collection of specific information on the musculoskeletal system to determine whether the potential or practising player can participate safely in sports.

The overall goals of sports-specific PPE include:

- the identification of impediments to participation (for example, coronary disease, asthma);
- uncovering of conditions predisposing the athlete to injury (for example musculoskeletal abnormalities and previous injury);
- the prevention of injury through a prescribed corrective program; and
- maximisation of performance

(Vicenzino & Vicenzino 1996; Kibler et al. 1989).

There is evidence that PPE performed by multiple examiners (for example, medical practitioner, physiotherapist, exercise physiologist, coach) in a station situation more effectively identifies musculoskeletal and other risk factors for injury than one performed by a single physician (Durant et al. 1985, cited in Vicenzino & Vicenzino 1996). However, the cost of screening by multiple specialist practitioners would be prohibitive for recreational players unless group screening sessions were organised. It is recommended that PPE, whether conducted on a group or individual basis, should be performed 4-6 weeks before commencement of the season to give sufficient time for deficits in strength, endurance, power, anaerobic and aerobic fitness and flexibility to be addressed by specific programs (Vincenzino & Vincenzino 1995; McKeag 1989).

Because of the cost of PPE, Kibler and colleagues recommend that the focus of the pre-participation examination should include both a medical and a musculoskeletal examination. The latter should be based on those aspects of athletic fitness that can be easily and efficiently measured, and confined to measures relating to the sport of interest to the athlete (Kibler et al. 1989).

The authors developed a method of testing for flexibility, strength and endurance and trialled it in a group of 2,107 athletes participating in a variety of sports from junior high school to the college level. Males were significantly stronger than females on all strength tests and females were more flexible than males on all flexibility tests. The tendency in both males and females was that tightness in musculoskeletal areas corresponded to areas of tensile loads applied during a particular sport, indicating sports-specific adaptations. For example, upper body athletes (tennis players, golfers, baseballers, swimmers etc.) were tighter than were lower body athletes (footballers, basketballers, soccer players etc.) in dominant shoulder internal rotations and significantly looser in dominant side external rotations. The authors hypothesise that attention to flexibility deficits in males and strength and endurance deficits in females should reduce the risk of muscle and tendon injury, although there is currently no research evidence to support this hypothesis. Also, sports-specific maladaptations can be identified in PPE exams and tailored conditioning programs instituted to rectify them.

Since success in tennis depends on a variety of factors, including the physical performance characteristics of the players, standardised testing can provide a useful supplement to subjective coaching appraisals (Groppel & Roetert 1992). Also, by identifying the physiological performance characteristics advantageous to successful performance in tennis, a coach can design a training program to optimise improvements in desired traits.

Although there is currently no research evidence to show that PPE is an effective method of ensuring safe participation in sport, there is general support for the development of tennis-specific PPE in the sports medicine literature (Kibler et al. 1988; McKeag 1989; Groppel & Roetart 1992; Nirschl & Sobel 1994; Chandler 1995; Vincenzino & Vincenzino 1995). It is believed that information from the PPE combined with injury records provide a better understanding of the specific risk factors for injury in tennis and the building blocks for well-designed conditioning programs.

The Australian Institute of Sport, Olympic Athlete Program and the Australian Sports Injury Prevention TaskForce have sponsored the development of a pre-participation examination for all sports including tennis. The protocols for this examination are now available in booklet form and the screening has been utilised by Tennis Australia at the elite and sub-elite levels for the last few years. All state squad players from 12 years and up have access to this screening and reports and exercise and training recommendations are provided to each player. Results from screenings being undertaken around Australia are sent to Tennis Australia's Sports Medicine Consultant and players' medical and musculoskeletal profiles are recorded on a database. This database will ultimately assist Tennis Australia to identify the 'ideal' musculoskeletal parameters of tennis players, of various age groups, and assist in developing recommendations and strategies for injury prevention. At the elite professional level, the Women's Tennis Association (WTA) and the Association of Tennis Professionals (ATP) TOURs require their players to undergo an annual screening examination. (Personal communication, Kathy Martin, Sports Medicine Consultant, Tennis Australia).

Recommendations for further research, development and implementation

- Extend pre-participation screening and tailored pre-season conditioning programs to a wider group of serious players and evaluate the protective effects of these programs.
- Continue to research assessment measures that are tennis specific to improve pre-participation evaluation instruments.
- Systematically evaluate the injury prevention efficacy of the current pre-participation evaluation program for elite and squad tennis players.

8.2.2 Training and conditioning

Fitness is a basic requirement for proper athletic performance and is believed to protect the body against the physical stresses and strains that are a normal part of athletic competition. Tennis is characterised by periods of intense activity with intermittent periods of rest and demands both anaerobic and aerobic fitness. The game also demands power, endurance, strength and balance. The sprinting, stopping, starting and bending nature of the game puts repetitive demands on the musculoskeletal system. There is currently no research evidence to support the proposition that well-conditioned athletes are less likely to be injured than unfit athletes but it makes inherent sense that athletes in good physical condition are less susceptible to injury.

Although epidemiological evidence is lacking, it appears that most recreational tennis players do not participate in any structured tennis training and play without any physical preparation (Nirschl & Sobel, 1994). Chard and Lachmann (1987) reported that more than 25% of the players of racquet sports they assessed prospectively (106 injuries) over one year at an English sports injury clinic had taken up a racquet sport in the previous three months. Most of these players had only started playing a few weeks prior to injury and some players were injured in the first match. The authors suggest a need to improve the 'education of new players' to try to reduce the risk of injury. There are no other studies that discuss the influence of lack of training and conditioning on injury among recreational tennis players in the literature.

The level and adequacy of fitness and conditioning among elite tennis players is better, but not extensively, studied. Chandler et al. (1990) compared the flexibility (sit and reach, quadricep, hamstring, gastrocnemius, shoulder internal and external rotation) of a group of 86 junior elite tennis players with that of 139 athletes involved in other sports. The tennis players were significantly tighter in sit and reach flexibility and internal rotation in both shoulders and significantly more flexible in external rotation in both shoulders. The authors suggested that the flexibility differences between the groups indicate sport-specific adaptations to the muskuloskeletal demands of the sport among tennis players. They recommended that elite, young tennis players undertake a sport-specific flexibility program to optimise their performance and protect them against flexibility-related maladaptations that make tennis players vulnerable to injuries, particularly shoulder and low back injuries. The authors suggest that tennis players perform a whole body stretch before activity and a shorter sport-specific stretching program after activity or vice versa if it is more convenient.

In a later study, Chandler and his colleagues tested 24 college tennis players for bilateral shoulder internal/external rotation strength (Chandler et al. 1992). They found that subjects produced significantly more torque and power in internal rotation in the dominant arm compared to the non-dominant arm but there were no significant differences in external rotation on any measurements. The authors concluded that the imbalances in strength of the internal and external rotators of the dominant arm may lead to shoulder overload injuries and recommended that tennis conditioning programs should include external rotation strengthening exercises (Chandler et al.1992).

Kibler et al. (1988) attempted to provide a detailed profile of elite tennis players and their fitness levels. Their investigation was guided by epidemiological research that showed a high level of overload injuries among tennis players and their belief that a well-conditioned musculoskeletal system is more able to tolerate athletic demands without failure. The authors investigated four groups of US and international elite juniors drawn from special training programs organised by the United States Tennis Association; the English National Training Centre, the Swedish Training Centre and full-time residential students at the Bollettieri Tennis Academy, Florida. The 97 participants were nationally ranked players in their age divisions, and many had won national championships. They were surveyed to evaluate playing history, training habits and injury incidence and rehabilitation and subjected to a tennis-specific musculoskeletal exam.

The authors found a high level of injuries, predominantly overload injuries, in all four groups. When the playing and training programs of the four groups were compared, it appeared that too much play or too much practice was not the sole or even the most important cause of the injury problems. They offered two other possible explanations for the injury patterns observed among players.

First, the large number of overload injuries, particularly in the back, shoulder and hamstrings, and the high proportion of abnormal tests results indicate that playing and practising tennis does not, of itself, confer sufficient fitness and conditioning for the game. In fact, the authors concluded that tennis play causes strains and adaptations that make players more vulnerable to injury, particularly overuse injury. They recommended that, in addition to playing tennis, extra conditioning is needed to correct the deficiencies in flexibility and strength highlighted in the physical exam, particularly posterior muscle flexibility and upper body strength.

Second, only 30% of athletes reported conditioning practices that were of sufficient time, type and breadth to confer 'total' conditioning for optimum performance. Also, the large number of inflexibilities found in the examination indicated a problem with technique rather than training time because players reported what appeared to be an adequate amount of flexibility training. The authors recommended flexibility, strength and endurance training for all participants who want to play tennis at frequent intervals. They also highlighted the need for more research into the exact composition of the 'ideal' conditioning program for tennis players.

Nirschl and Sobel (1994) provided preliminary data on the fitness of national junior level players involved in the United States Tennis Association (USTA) player development program. They reported that of the first group of nationally ranked players who were tested 70% had shoulder imbalances or injury and that elbow, knee and ankle abnormalities and difficulties were common as were postural and abdominal problems and flexibility deficiencies. They believed that there are clear indications that tennis players at all standards of play have physiological vulnerability problems that predispose them to injury. They recommend that musculoskeletal, strength, endurance, flexibility, aerobic and anaerobic deficiencies in tennis players need to be identified through fitness evaluations and addressed by individual supplemental exercise programs.

Fricker and McGuire (1986) speculated that the dominance of lower limb injuries over those involving the upper limb and trunk among the elite young Australian tennis players they monitored over a four year period (1982-85) was partly attributable to the lack of attention to lower limb fitness programs. The authors indicated that the Australian Institute of Sport had adjusted the training of this group to include pre-participation conditioning which included specific ankle and knee proprioceptive and strengthening exercises and a fitness program which includes endurance work such as running 20-30 minutes three times weekly in correct footwear. This program was specifically designed for athletes who compete and play on 'Plexipave' and rubber overlay surfaces. There was a decrease in all injuries, including lower limb injuries, in 1985 after the introduction of the new program. However, the authors could do no more than speculate that the changes in training may have contributed to the downturn in injuries because no controlled evaluation was conducted.

Chandler (1995) outlines a 'total' conditioning program for the competitive junior and professional tennis player which aims to strengthen areas in high demand and correct deficits. He divides into three components:

1. Basic physical fitness to develop muscular strength (lower and upper body exercises, weight training, abdominal strength drills, medicine ball drills and calisthenic exercises); build cardio-respiratory endurance (treadmill, cycling and stair stepping); increase muscle endurance; and develop and maintain full flexibility.

2. Sport-specific athletic fitness and movement training using quick explosive exercises and sprint/interval training which mimic the movements in tennis plus drills (with medicine balls and racquets) which condition the body as a kinetic chain transferring ground reaction forces through the legs and trunk to the shoulders.

3. Prehabilitation exercises to improve strength, endurance and range of motion in the musculoskeletal areas that are at high risk of injury – the elbow, wrist, shoulder, low back, hip and calf. These should be tailored to the individual needs of players.

He recommends that recreational players can also benefit from prehabilitation exercises because they may enhance their ability to continue to play the sport as they get older.

Periodisation of training – altering the activity and the volume, intensity and frequency of training according to the time of the year and the players tournament schedule and fitness level – is also identified as an important aspect to be considered when planning the year-round conditioning program for the elite competitive player (Groppel & Roetart 1992; Chandler 1995).

Nirschl and Sobel (1994) recommend that training programs for ‘serious’ competitive tennis players should include the following:

1. A quality fitness and performance examination.

2. Supplementary exercises to eliminate deficiencies identified in the fitness and performance examination.

3. Implementation of equipment changes, counterforce bracing, or orthosis to supplement any deficiencies noted.

4. Gradual build-up of training to develop stroke mechanics and competitive strategy.

5. Although highly individualised, the following basic schedule for serious tennis play is suggested:

    a) structured tennis, 3 x 2-3 hour sessions per week
    b) supplementary exercise (2 x 1 hour sessions weekly)
    c) tennis play according to skill level at a frequency and intensity that does not produce overuse injury
    d) fitness re-testing every 6 months.

More research is needed to determine the contribution of ‘best practice’ tennis-specific conditioning programs to injury prevention. Randomised controlled trials are possibly the only way to control all the individual and situational variations that complicate research on this issue.

As already mentioned published information on the fitness level of players at the club level is lacking. Well-conducted training programs at any level require advanced planning and good knowledge of the requirements of the sport and the bodies of individual players (Peterson & Renstrom 1986 in Backx 1991). For these reasons it is important that club level coaches are accredited (at least to Australia Coaching Council Level One standard) and continuously update their knowledge and skills. Tennis Australia is currently establishing a Coaches Internet site and regularly disseminates information to coaches.

Recommendations for further research, development and implementation

- Simple pre-season fitness testing should be conducted on players participating in competitive tennis at the inter-club level, four to six weeks prior to the start of the season.
- All competitive and recreational tennis players are advised to undergo a graduated skills development and training program (which includes cross training), guided by results of an initial fitness test.
- Players should consult an accredited tennis coach on their individual training requirements.
- Initiatives to increase the awareness of players and coaches of the injury consequences of training errors (including over-training) should be continuously developed, and refined as new knowledge becomes available.

- Controlled evaluation studies should be conducted to determine ‘best practice’ conditioning and training programs that develop the skills and fitness necessary for competitive tennis and protect players from injury.

8.2.3 Warm-up, stretching and cool down

“Warm-up” is a term which covers the light exercise, stretching and psychological activities that are undertaken just prior to sporting activity to increase ‘readiness to perform’ (Best & Garrett, 1993). The regime of warm-up to a light sweat followed by slow and relaxed stretching, immediately prior to exercise, is generally recommended to athletes to enhance performance and reduce the risk of musculotendinous injury, particularly muscle tears (Safran et al. 1989).

Literature reviews by Safran et al. (1989) and Best and Garrett (1993) concluded that there is a body of physiological evidence that shows that warm-up removes some of the physical stresses associated with exercise. Warm-up and stretching have been shown in laboratory studies to improve the range of motion of the joints, increase muscle, ligament and tendon elasticity (thus requiring a greater force and degree of lengthening to tear muscle) and promote heat transfer (Safran et al. 1989; Best & Garrett 1993).

On the basis of current clinical and experimental evidence, Safran and his colleagues were prepared to recommend that warm-up and stretching routines are essential to the prevention of muscle injuries in sport. Best and Garret (1993) were less inclined to provide such an unqualified endorsement. They concluded that it was ‘reasonable to accept’ on the basis of current evidence that warm-up may play a role in the reduction of the incidence and severity of musculoskeletal injuries. Both research groups recommend that well-controlled epidemiological and experimental studies are needed to fully evaluate the protective effects of warm-up.

McGrath and Finch (1996) recently reviewed published studies on the effectiveness of warm-up and stretching as a countermeasure to running injuries and found that the epidemiological evidence was inconclusive. In fact, the weight of research evidence suggested that warm-up and stretching had either no effect or a negative effect on the risk of sustaining a running injury. However, the authors alluded to a number of methodological weaknesses in the studies they reviewed, particularly the lack of information on the type and duration of the warm up, cool down and stretching routines used by participants. They suggested that a possible explanation for the conflicting results in the literature is that some warm-up regimes and practices may protect against injury while others may not (or may even cause injury).

The specific contribution of warm-up (including stretching) and cool-down to tennis injury prevention is not well studied. In the prospective component of a study of racquet sport injuries treated over a one-year period at an English sports clinic it found that 20% of the 106 racquet sports injuries (including tennis injuries) were sustained within a few minutes of starting play (Chard & Lachmann 1987). This finding suggested to the authors that warm-up activities were poorly executed or not done at all by some players, but comparative data on the injured players’ warm-up and cool-down routines were not collected. In a more recent retrospective study of 100 young tennis players aged 9-18 years from 5 English clubs, Reilly and Collyer (1994) observed a significant relationship between lack of warm-up and injury ($P<0.01$), based on self reported data. A lower injury rate (31%) occurred in those warming up for 5 minutes or more compared to those who warmed up for 0-5 minutes (73%). According to the authors the protective effect was more pronounced among the group warming up for 10 minutes or more but these data were not reported. By contrast, Kamien reported that he found no association between the occurrence of either lateral or medial tennis elbow and type or length of warm-up in his retrospective survey of 260 Western Australian club-level players.

The Orientation to Coaching Manual published by Tennis Australia (1996) advises players to warm-up to increase body temperature and reduce the risk of tearing and straining muscles. The manual recommends jogging for 2-3 minutes to raise a light sweat. The manual also advises that stretching reduces muscle tension, prevents tendon injuries and increases flexibility. The manual describes specific stretching activities for tennis players including forearm, upperarm, quadriceps, leg, calf and Achilles stretches. Cool down (light jogging and stretching after exercise) to remove waste products and reduce muscle soreness is also recommended.

Rigorous controlled trials are obviously required to determine whether warm-up, stretching and cool down routines are effective injury prevention measures. These trials should also address such issues as the optimal time for warm up and cool down, whether individualised programs are needed for players in different age and sex groupings and whether customised warm-ups are required for different sports.

Recommendations for further research, development and implementation

- All players should routinely warm-up, cool down and stretch before and after every game and training session.
- The specific needs of the injured tennis player should be considered when warm-up, stretching and cool down regimes are developed.
- The injury protective effects of warm-up, stretching and cool-down require evaluation in controlled trials.

8.3 ENVIRONMENTAL FACTORS

Environmental conditions that may contribute to injury include the weather and the condition and type of playing surfaces. Tennis can be played indoors and outdoors in a range of temperatures and on a variety of surfaces and it is important to consider the influence of environmental factors on injury risk.

8.3.1 Weather conditions

Extreme heat

Tennis is mostly played in summer in conditions that range from comfortably warm to oppressively hot. The 1994 Australian Open was played in over 38ºC heat and the centre court surface air temperature regularly approached 54ºC (Bergeron et al. 1995). These conditions would tax even the best-conditioned and fittest players. Hutchinson et al. (1995) reported that the only truly life-threatening injuries cared for throughout the six-year period of injury surveillance at the US Boys Tennis Championships were heat-related disorders that occurred in warm and humid conditions in two tournament years. Eight players were affected with heat exhaustion and one case accounted for the single episode of injury over the six-year study period that required emergency transport to hospital, two players experienced heat-related cramps.

Male and female tennis players can expect to lose, via sweat, between 0.5 and 2.5 L of water during each hour of play (Bergeron et al. 1995). The amount of water loss depends on a range of individual factors such as environment, intensity of play, acclimatisation, fitness, gender and age.

Therminarias et al. (1995) studied the physiological responses of 23 intermediate level female tennis players playing their most feared opponent to a highly competitive match of two hours set duration in summer (ambient temperature (28.3±0.7°C) under standardised conditions (diet, ambient temperature, intensity, duration). Three of the players stopped before the end of their matches because of cramps and one because of heat stroke. Comparisons of biological values between the cases (heat affected players) and controls (non-heated affected players) suggested to the authors that the physiological state of a player before the match was the largest influence on the occurrence of heat cramps. Pre-match, post-match and one-week follow-up tests on the three women who had cramps showed that a deficiency in magnesium pre-existed in one woman, a deficiency in calcium was found post-match in the second (who was usually on a low calcium diet), and a deficiency in iron pre-match in the third (who was found to have anaemia in the one week follow-up test). These mineral deficiencies are all linked to cramping. This study was based on a relatively small sample of women and the findings may not be generalisable to other tennis populations.

Evaporative heat loss through sweating is the most effective on-court mechanism for dissipating heat in hot weather. If adequate fluid intake is not maintained, a player's thermoregulatory capacity is diminished leading to premature fatigue, significant loss of performance and ultimately heat exhaustion (Bergeron et al. 1995). There are four recognisable heat disorders in the exercising athlete: heat cramp, heat syncope, heat exhaustion, and heatstroke (Murphy 1988). A summary of the symptoms associated with these disorders and the recommended treatment can be found in Appendix 3.

Bergeron et al. (1995) compiled a set of recommendations (partly based on several recently published reviews) for fluid replacement and carbohydrate supplementation in tennis players competing in a hot environment. First, players who intend to play in a hot climate should undergo a process of acclimatisation of at least 7 to 10 days duration which should involve training or competing daily for 1 to 2 hours in the same heat. Second, players should imbibe sufficient CHO-electrolye drink at each changeover to feel comfortably full whether or not thirst is satiated (for matches less than one-hour long water consumption during play should be sufficient provided the player begins the match euhydrated and with glycogen stores replenished). Third, after a match a player should replace lost fluids and electrolytes while consuming carbohydrates. The authors recommended carbohydrate-electrolyte drink over plain water because it has been shown to promote fluid absorption better. Some research on fluid replacement in players is to be conducted at some challenger events in Australia in 1999, with the approval of Tennis Australia (personal communication, Kathy Martin, Sports Medicine Consultant, Tennis Australia).

It should be noted that the recommended 7-10 days acclimatisation period is often not practical, either because of players' other commitments or the extra expenses involved. In these circumstances careful monitoring of fluid loss and replenishment during tournaments in hot conditions is of crucial importance. Other actions that players can take to minimise heat-related injury include: wearing loose, light, porous and pale-coloured clothing to facilitate evaporation of sweat and to minimise heat absorption; and the use of a sunscreen to prevent sunburn.

Nirschl and Sobel (1994) recommend these safety measures to competition event organisers, clubs and associations to reduce the risk of injury to players competing in hot weather:

- Cancel matches in hot and humid weather.
- Extend rest periods when environmental factors dictate.
- Make sun-free enclosures available during between-game change overs.
- Supply plenty of water [and CHO-electrolyte drinks – see discussion above].
- Allow specific accommodation for medical consultation and medical time-outs during the course of play.

The Australian Open "Extreme Heat Policy" announced late in 1997 defines extreme heat as occurring whenever the temperature actually reaches 40 degrees Celsius, according to the Bureau of Meteorology. The following guidelines apply in extreme heat during the Australian Open:

1. The referee has the right to suspend the commencement of matches if played outdoors.

2. All matches currently in progress must continue until their conclusion.

3. The guidelines apply to all matches whether men's, women's, junior or senior, whether singles, doubles or mixed doubles, and to all stages of the Tournament.

4. The referee shall endeavour to re-schedule suspended matches later in the day when conditions are cooler.

5. With respect to Centre Court where there is a roof, there will be an addition to the "General Policy for Opening and Closing of Stadium Roof".

(Tennis Australia 1998)

The Women's Tennis Association (WTA) TOUR also has an Extreme Weather Condition Rule, which is implemented in all sanctioned WTA events, and Women's International Tennis Tennis Federation events date (personal communication, Kathy Martin, Sports Medicine Consultant, Tennis Australia). The Australian Open also adopted this rule for the women players and junior Boys and Girls in 1998 and 1999, the only Grand Slam event to do so.

Under this rule extreme weather conditions are defined at such times that heat, as measured by a Heat Stress Monitor, meets or exceeds a heat stress index of 28 degrees Celsius (82 degrees Fahrenheit). If a Heat Stress Monitor is not available, extreme weather conditions are then defined by the danger zone which is equal to or above the apparent temperature of 90 degrees Fahrenheit. The WTA TOUR Primary Health Care Provider (PHCP) and the WTA TOUR tour director have the authority to determine if the Extreme Weather Condition Rule will go into effect during a tournament. If it is so determined, a 10 minute break will be allowed between the second and third sets, if one player in a game requests it. There may also be a delay in the starting time of the matches scheduled for play that day. Measurements are taken four times during the day by the PHCP: ½ hour before match play begins for the day, at 1.00 p.m., at 4.00 p.m. and ½ hour before the evening session begins.

PHCPs, on site at every WTA TOUR event, and at all ITF $US50,000 and US $US75,000 events provide ongoing education about the potential dangers of heat illness and signs are placed in the locker rooms, on toilet doors and on the drinks fridges to alert players to the preventive measures they can take. These types of education and awareness-raising initiatives should be adopted at the club level so that all tennis players are informed about the prevention of heat illness.

Injury risk related to the performance of tennis surfaces and balls in different weather conditions

The performance of the tennis surface in different weather conditions also needs to be considered. Rain may lead to a slippery surface that can increase the risk of fall injuries. The ambient temperature and the court surface can also affect ball speed and performance. On a hot day, balls are livelier because the pressure of the ball goes up and humidity slows the ball down. In wet weather the ball cover absorbs water making the ball heavier. Tennis players who have elbow problems are advised to avoid playing when the ball is wet and in windy conditions, if possible. On hard courts, the ball tends to skid which makes it faster whereas on clay courts the ball bites into the ground causing it to slow up. Players who don't adjust their game to changed playing conditions risk injury (Cleary 1997).

Recommendations for further research, development and implementation

- Extreme heat policy and rules need to be developed at the local club and inter-club competition levels.
- Clubs should provide umbrellas and ice-chests on-court, and supply water and 'sports' drinks (with 4%-8% carbohydrate content).
- Players should learn how to monitor their fluid intake during games by weighing themselves or by noting any reduction in the amount and concentration of urine output in relation to fluid intake (oliguria). Players should replace fluid and electrolyte loss by consuming 400-600 mls of fluid (2-3 standard glasses) at least 30 minutes before play and 200-300 mls (1-2 glasses) every 15 minutes during play (at change of ends).
- Education & signage about measures to prevent heat illness should be provided at the club level.
- Players should use a broad spectrum sunscreen.
- Research should continue on player diet and hydration issues.

8.3.2 Playing surface

Tennis developed as an outdoor game played on natural turf. Two of the main reasons for the development of artificial playing surfaces were the desire to make tennis less dependant on external influences, for example the weather, and the need to reduce operating and maintenance costs (Nigg & Yeadon 1987). The change to artificial surfaces has brought with it some unexpected spin-offs. In some sports, for example track and field, performances appear to have improved. On the other hand, there is a body of evidence pointing to change in the type and frequency of injuries with the introduction of new surface materials (Nigg & Yeadon 1987).

Today, tennis is played all-year round on a variety of surfaces from concrete and asphalt to clay, indoor carpet, synthetic materials and grass. Kachel (1990) reported that the main types of tennis courts in Victoria are lawn (25-30%), artificial lawn (5-10%), red porous (30-40%), synthetic (10-15%), asphalt and concrete (20-25%) and others (5%). The four major tournaments around the world are played on different surfaces: Australian Open – 'Rebound Ace'; French Open - clay; Wimbledon - lawn; and the US Open – 'Deco Turf' and 'Plexipave'.

It is generally assumed that the various surfaces cause problems with 'reading' the ball and may impact on the safety of the game. The speed of play on clay is slower because the ball bounces with a much higher trajectory allowing the player more time to strike the ball. Clay surfaces are 'forgiving' (softer) and are believed to cushion the knees and legs, however the longer rallies, extra running and bad bounces (depending on upkeep) may lead to more sliding-related and other injuries (Lehman 1988; Kibler & Chandler 1994). Grass surfaces produce higher ball speeds and frequent irregular bounces that are also believed to place more stress on the upper extremity and to contribute to collision injuries but, as with clay, the legs are better protected (Lehman 1988; Kibler & Chandler 1994). The ball speed is higher and the bounce lower on hard court or wood surface and these characteristics are believed to place more stress on the upper extremity during stroke production and cause overuse problems to the legs (Lehman 1988; Kibler & Chandler 1994). The forces generated and speed of play on indoor carpet surfaces are dependant on the under surface used (Lehman 1988; Kibler & Chandler 1994).

Nigg and Segesser (1988) reviewed the effect of sports surfaces on injuries in American football in preparation for their own investigation on the influence that tennis surfaces have on the occurrence and frequency of tennis injuries. The authors analysed and quantified information in 32 studies published between 1971 and 1987. They found that there were more non-severe injuries (for example abrasions and bruises) on artificial turf than on natural grass, and that severe injuries in body sites other than the lower extremity occur about as often on artificial turf as they do on grass. There was conflicting evidence on whether there were more, less or the same number of severe injuries in the knee and ankle joint on the two types of surface but the authors concluded, on the balance of evidence, that they appeared to be about as frequent. They commented that most studies were case series and the quality and comprehensiveness of the studies varied, making comparisons difficult.

[A later meta-analysis of the epidemiology of surface-related injuries in American football by Skovron et al. (1990) indicated that the risk of ankle and knee injuries was greater on synthetic turfs. The injury rate for knee sprains was 0.8 per 1,000 athlete exposures on natural surfaces compared to a pooled rate of 1 per 1000 athlete on artificial turf. The relative risk for ankle sprains among American football players was 0.45 per 1,000 for synthetic AstroTurf versus 0.32 for grass (Skovron et al. 1990)].

Nigg and Segesser (1988) subsequently conducted their own postal survey of 4000 tennis players in Switzerland. The response rate was only 25% (1,003 tennis players) and, therefore, the results are probably biased. The authors found that 52% of respondents had experienced pain and/or injury at least once per season (defined as 6 months of play). There were 653 reports of pain/injuries to the upper extremity, including the head and upper back/trunk and 990 reports of lower extremity injury including low back injury/pain.

The authors made the assumption that pain/injuries to the lower extremities, lower back and hip region could be associated with the playing surface. The subsequent data analysis showed that players who played mostly on clay and synthetic sand had a significantly lower frequency of lower extremity injury compared to those who played predominantly on synthetic surfaces, asphalt, felt carpet and synthetic grill. Additional analyses suggested that frequency of activity had no bearing on this result nor, surprisingly, did the relative compliance (cushioning or 'give') of the surface.

The main difference between the clay and synthetic sand and the four other surface types was their frictional behaviour (at the interface between player's shoes and surface). The authors speculate that, in general, tennis courts with low frictional resistance (but not so low as to cause slipping) cause fewer injuries than surfaces with high frictional resistance which causes 'sticking'. Based on their own research and the published literature, they concluded that the optimal value for the translation frictional coefficient of a surface for tennis would appear to be about 0.5.

However, previous research by one of the authors showed that 'frictional propert
constant but vary under different loading, which complicates the issue. Nonetheless, the frictional value recommended for tennis is similar to the optimal values, based on objective and subjective assessments, recommended for other sports (0.5-0.7). The authors concluded that more research is needed to establish the optimal rotational friction value of tennis surfaces. Also, they recommended that prospective, controlled research is needed to investigate the effect of compliance ('give') of surfaces because this characteristic has been shown to influence injury rates in other sports (for example aerobics and dance).

Steele (1990) reviewed the body of evidence that points to a relationship between court surface and the frequency and type of sports injuries but concluded that definitive evidence was lacking and many aspects of the issue requires further investigation. She pointed out that the evaluation of the suitability of a surface for a particular sport is a complex matter. Decision-making requires consideration of the functional needs of the sport and the durability and upkeep costs of the surface, along with detailed performance information on the material properties of the surface that may impact on safety and comfort. She identified several characteristics of playing surfaces that appear to have an impact on injury incidence: stiffness (shock absorbency); resilience (degree of hardness or softness); slip-resistance (frictional properties); heat absorption; colour and reflectivity; the effect of surface uniformity on game speed and impact forces; toxicity and fire performance. She recommended the establishment of performance values for specific sports to guide administrators in their choice of surface/s but stated that the establishment of such values requires extensive laboratory and field research.

Although synthetic surfaces have practical advantages, there is currently a paucity of information to assist tennis administrators and/or owners of facilities to select the most suitable surface/s from the range on offer. No matter what type of surface is installed, tennis courts should be regularly checked and maintained to eliminate wear, tear, cracks and other surface hazards, and the immediate environment should be kept clear of collision and trip hazards.

Recommendations for further research, development and implementation

- Risk management/sports safety plans, that include measures to eliminate or ameliorate environmental and other injury hazards, should be developed, implemented and monitored by tennis facility owners (including local councils, associations, clubs, schools and churches) and managers. Guidelines and support for the development of these plans should be available.
- Equipment, seating and advertising should be kept away from court boundaries, net posts should be padded.
- Tennis surfaces should be diligently maintained and regularly checked for hazards such as hollows, cracks and wear.
- Further laboratory and controlled field research is needed to determine the optimal safety performance values for tennis surfaces.

8.4 APPROPRIATE TENNIS EQUIPMENT

Compared to other sports tennis requires very little equipment. Tennis equipment basically consists of a tennis racquet, balls and footwear. Each piece of equipment has been implicated in the occurrence of injury, particularly overuse injury, and it is suggested in the literature that the appropriate choice of equipment may reduce the risk of injury and aid rehabilitation from injury.

8.4.1 Racquets

Racquets and overuse injury

Tennis racquet design was fairly standard until the 1960s. The boom in popularity of tennis during the 1970s led to racquet manufacturers investing large amounts of time and money into the construction of more efficient racquets. The use of wood is outdated and today's racquets are made from graphite, graphite/fibreglass composites and viscoelastic polymers, titanium and aluminium. Modern materials provide the player with more hitting power than was available from the wood rac

Racquets vary in size and shape although the development of the large-headed racquet (which provide increasing string area and a larger 'sweet spots') led tennis authorities to restrict the size of the frame. The length is currently limited to 81.28cm and the width to 31.75cm. The strung surface must not exceed 39.37cm in length and 29.21cm in width (Australian Sports Commission, 1997). Compared to the racquet of the 1980s, today's racquets are 64% bigger and 16% thicker, yet 20% lighter (Arthur, 1992). In a highly competitive market design innovations continue to be developed with the main aim of increasing power play, although there appears to be some awareness of overuse injury prevention. For example, one manufacturer is experimenting with a perimeter weighting system and rectangular geometry (a paddle-shape). It is claimed that both these innovations reduce racquet 'twisting' (which is believed to be associated with the development of tennis elbow) while maintaining racquet stiffness and power.

Today's tennis racquets most commonly incorporate a Y-shaped throat configuration which is believed to reduce air resistance (Field & Altcheck 1995). Manufacturers generally classify racquets as stiff, medium and flexible but there are no standards for these classifications. With a flexible racquet, energy is lost as the shaft bends in reaction to impact, whereas a stiff racquet will not bend as much and, consequently, not as much energy will be lost resulting in faster ball rebound velocity (Groppel 1992).

The relative contribution that torque and vibration make to the incidence of tennis elbow has been extensively discussed in section 6.1.2. It would appear, from the available evidence, that racket torsion (the twisting of the racquet along its axis when the ball is miss-hit) plays a larger role than vibration in the development of tennis elbow. However, vibration may exacerbate the condition in the injured player (Renstrom 1990; Kamien 1990; Nirschl & Sobel 1994). A number of racquet characteristics—material, head size, weight, grip size and type and tightness of strings—appear to affect, to a greater or lesser degree, the vibration and torque forces generated at ball impact and are therefore believed to contribute to arm injuries in tennis players.

Racquet material

There is some debate in the literature about whether the construction of tennis racquets in newer materials, such as metal, graphite, fibreglass and ceramics that supposedly absorb ball impact vibrations less effectively than wood, have increased the incidence of tennis elbow (Wardsworth 1987). Kamien (1990) could find no epidemiological evidence in the research literature on tennis elbow that showed an increase in the incidence of tennis elbow in the period since the introduction of metal and synthetic racquets. He noted that the only finding from laboratory research on which there is general agreement is that a standard sized wood racquet produces lower vibrations at the head of the racquet with off-centre ball impact than an oversized metal racquet. His own research led him to believe that different types of rackets affect players differently. Up to 20% of the 148 tennis elbow sufferers in his survey of 260 recreational tennis players attributed the onset of elbow symptoms with changing to a new type of racquet, several of whom had changed from wooden to a new graphite racquet. By contrast, 37% of the same group reported that a change of racquet, most commonly from standard wood to mid-size graphite or composite, was helpful in alleviating elbow pain.

Both Kamien (1990) and Renstrom (1995) concluded that there is no definitive or consistent evidence to implicate any particular type of frame material or weight of racquet with an increased or decreased risk of arm overuse injury. However, Kamien advised players with a tennis elbow to consider using a racquet made of flexible ('forgiving') material, either one which contains a high proportion of fibreglass which transmits less jar or the mid-sized injection moulded racquet advocated by Carroll et al. (1988, cited in Kamien 1990). Renstrom (1995) has shifted his recommendation from graphite frames (which have good vibration dampening qualities) to ceramic composition frames for arm-injured players. He believes that the increased flexibility of ceramic frames decreases the stress on the injured arm. Both authors recommend lighter weight racquets, that are not head heavy, for athletes with elbow and shoulder problems (Kamien 1990; Renstrom 1995).

Racquet head size

Most racquets are now offered in mid-size or large size head sizes. Making a racquet 20% wider reduces the twisting potential by almost 40% and may result in up to a four-fold increase the effective hitting zone on the racquet face (Groppel 1992). If the ball hits in the centre of percussion the net force on the hand following impact is negligible (Groppel 1992). The centre of percussion ("sweet spot") is defined as the point of the racquet which, when hit, will keep vibration impact from being transferred to the hand, and consequently will maximise the energy available to the ball

(Renstrom 1995). However, when the ball hits off-centre, the racquet tends to twist along its axis. This twisting effect, or torque, can affect the shot and can also cause serious strain to the forearm muscles as they contract to control the excessive racquet movement (Groppel 1992).

Hennig et al. (1992) used miniature accelerometers at the wrist and elbow of 24 tennis players to evaluate impact-induced vibration from 32 different racquet constructions in a simulated backhand stroke. The authors found a more than four-fold reduction in the amplitude of vibration between the wrist and elbow. However off-centre ball impacts, compared with centre-ball impacts, resulted in approximately a threefold increase in load of the arm. Increased racquet head size was found to reduce arm vibration. Elliot et al. (1980) also reported a reduction of vibration with increased string area for off-centre impacts in oversized racquets compared with conventional racquets.

Kamien (1990) reported that while there was general agreement that oversize racquets absorb vibrations better than conventional size racquets there was also agreement that oversize racquets have a greater potential for producing torque injury. He explained that the research of Berhang et al (1974) and Brody (1979) show that as force moves away from the longitudinal axis of the racquet, torque is imparted to the longitudinal axis. It follows, therefore, that the further away the force is from the axis (and the likelihood of this is greater in oversize racquets) the greater the torque. Nirschl and Sobel (1994) theorise that wide body racquets may increase the likelihood of arm injuries because they are stiffer and their use encourages an over-reliance on arm strokes because they allow players to make good shots without attention to correct footwork. The authors do not recommend a racquet-hitting zone greater than 710 cm^2.

String material and tension

Racquet string materials and tension have also been implicated in upper extremity injuries. Racquet strings can be made of gut (smooth muscle portion of sheep or beef intestine), nylon or other synthetic materials (artificial gut, graphite and oil filled) that offer many of the characteristics of natural gut.

Groppel (1992) reports that elite players assess that natural gut is superior to synthetics on a range of parameters: control, higher ball velocities after impact, lower vibration levels to the hand, and improved overall playability. However, natural gut is neither hard-wearing nor economical. Gut, thinner-gauge and the ‘soft’ synthetic strings are believed to transmit less vibration to the arm and are recommended for players with overuse injury.

Scientific testing shows that the impact (and consequent ball velocity) depends not only on the string type but also its tension and the racquet head size (Groppel 1992). Elliott (1988) analysed the effects of ball velocity resulting from different tensions of gut versus nylon string. Regardless of whether gut or nylon was used, ball velocity decreased when string tension went from 50 pounds to 65 pounds. However, when comparing gut string to nylon at the same levels of tension, he found that ball velocities following impact with gut string were superior. Brody (1985) showed that the higher the string tension, the greater the shock which has to be absorbed by the arm especially with off-centre hits. Therefore, it is generally recommended that players who have tennis elbow or other arm problems should string their racquets looser (Lehman,1988; Kamien 1990; Renstrom 1995). Lehman (1988) recommends that an injured athlete should adjust the usual string tension of his/her racquet downward by 3-5lbs. Renstrom (1995) warns that a racquet should not be strung too tightly, and recommends that all players string their racquets at between 50-55 lbs. of tension in order to avoid tennis elbow.

Damping material (vibration stoppers)

One method of reducing impact shock and post-impact vibration transfer to the wrist and arm (which is hypothesised to contribute to arm injury) is to use a damping material (vibration stoppers). A vibration stopper is a soft and light vibration-absorbing device (made of double-layered sponge, plastic or rubber) which is attached to the two main longitudinal strings near the throat of the racquet. They dampen the pitch of the pinging sound that occurs when the ball hits the racquet (Kamona 1990).

Tomosue et al. (1995) conducted a study using nine different 'Dunlop
vibrations of a racquet handle and the wrist joint during actual hitting in a tennis forehand drive and quantify the effectiveness of a damping material (double-layer sponge) in reducing impact shock and vibration transfer. Seven tennis racquets with different frame body width, face area, flexibility and string tension, and two tennis racquets with a damping material were selected. All racquets were the same weight and grip size. A single skilled male player was used as a subject. To record the vibrations, two accelerometers (one fixed to the racquet handle and the other to the lister tubercle) were used.

Results indicated that differences in frame body width, face area, flexibility and string tension had no significant effect on vibration amplitude but that the damping device significantly reduced the vibration amplitude in the racquet handle (p=0.01) and wrist joint (p=0.05). The researchers concluded that if maximal amplitude of vibrations is strongly related to inducing over-use injuries, there may be a positive effect if a tennis player uses a racquet with damping material (Tomosue et al. 1995).

One condition of Tomasue and colleagues' experiment was that only balls that hit the centre of the racquet strings were included. Brody (1988) reported similar favourable results from his experiments using an oscilloscope and a vibration frequency detector on the handle grip. However, he reported that when the ball was hit off-centre (the site of most tennis shots) the vibration stopper made very little difference to the level of vibration transmitted to the hand. This result suggests that vibration stoppers have limited value in the prevention and rehabilitation of arm injuries.

Grip size

Racquet grip size has been shown to affect the amount of racquet torque by a number of investigators but the evidence is not clearcut and recommendations are necessarily tentative. Both Berhang et al. (1974, cited in Kamien 1990) and Adelsberg (1988) used electromyography (EMG) to assess the different racket grip sizes on the muscle activity of the forearm and shoulder in selected groups of test subjects. Berhang and his colleagues found that an increase in grip size was associated with a decrease in electromyographic output and concluded that racquet torque is best controlled by using the largest comfortable grip. Adelsberg (1988) also found a reduction in the force change in the muscles with increasing grip size but concluded the reduction was not of significant magnitude to support the recommendation that a player with tennis elbow should change to a larger grip size. The latter study used more refined EMG equipment that did not involve the wires and cables that inhibited the movement of subjects in the study by Berhang and associates (Kamien 1990).

Hatze (1976) and Groppel (1984) observed that players whose racquet grip size was small in relation to their hand size tended to squeeze the grip tightly to maintain control on impact which resulted in a greater transmission of forces from the racquet to the forearm. Murley (1987) reported that the use of a larger grip was associated with greater dorsal flexion of the wrist and less tension on the origins of the forearm extensor muscles.

The epidemiological evidence is also inconsistent. Hang and Peng (1984, cited in Renstrom 1995) found that too large or too small a grip was associated with a very high incidence of tennis elbow. Gruchow and Pelletier (1979) reported that larger grip size was associated with higher incidence of tennis elbow in the older group (age 40-50 years) in their study. By contrast, Kamien (1988) found no association between tennis elbow and the use of a grip that was larger or smaller than the player's hand size in his survey of recreational tennis players. However, he reported that 84-94% of the players with tennis elbow in his study who had changed the size of their grip (either up or down) found it gave some relief from their elbow pain.

Most investigators recommend that players use the simple method described by Nirschl (1973) to estimate the circumference of the grip they should use. The measure is taken on the fourth (ring) finger along its radial border, from the tip of the finger to the proximal palmal crease. Kamien (1990) recommends that all players with tennis elbow should have the grip of their tennis racquet checked against their hand size and make the necessary adjustments. Nirschl and Sobel (1994) also emphasise the importance of players using the correct size grip but comment that if players want to deviate from the correct size for any reason they should err on the side of larger sizes because they provide more torsion control. They also warn that it is potentially harmful and inappropriate for children to use adult size equipment.

Cushion grip bands

The effectiveness of cushion grip bands in reducing impact shock and vibration transfer and slipping in tennis racquets was investigated by Hatze (1992). He reported that all of the cushion grip bands, but none of the cover grip bands, tested in the laboratory using an artificial arm (manusimulator) reduced impact shock and vibration transfer to the hand-arm system significantly ($p= 0.05$) but not substantially. He commented that his experimental results inferred that a more efficient way of reducing post-impact vibration transfer is to reduce the grip tightness to a level just sufficient for effective play. He recommended the use of cushion grip bands on the basis that it was reasonable to expect that a reduction in the transfer of vibrations to the player's hand and arm should have some cumulative beneficial effect on overuse injuries. However, he assessed that more biomechanical and other evidence is needed to definitively establish a causal relationship between impact shock and post impact vibration transfer and overstrain tendon injury, particularly 'tennis

Kamien (1990) recommends that players with tennis elbow, their doctors and physiotherapists should keep themselves informed about available innovations in handles and grips (such as non-vibration control racquets and the slip-on gel grip) and trial those that appear promising in terms of the reduction of vibration and other impact forces.

Racquet selection

Expert advice should be sought when selecting a racquet because the skills, physical abilities, injury experience and maturation of the player need to taken into account. Players may also have their racquets customised by the addition of: lead tape (that makes the racquet heavier and changes the balance point); synthetic or leather grips (to build up grip size); strings (gut, synthetic gut or synthetic); string tension; and stringalings (that help keep string tension constant and allow for more durability).

Nirschl and Sobel (1994) developed a set of guidelines, based on clinical and anecdotal data, which they recommend should be used by players when selecting a racquet, especially players with shoulder and elbow symptoms:

- Mid size racquet frame (580-710 cm^2 of hitting zone)

- Graphite or graphite composite frame such as graphite plus fibreglass or kevlar

  [note that Lehman (1988) reports that he has shifted his recommendation from graphite to ceramic composite for arm-injured players because of its greater flexibility characteristics]
- Medium to moderate flexibility of the frame
- Medium to soft string tension
- Proper grip size

Racquet-related acute injuries

Tennis racquet 'hits' are a significant cause of acute tennis injuries presenting to hospital emergency departments, particularly in children. In Victoria, hospital emergency department case narratives reveal that 13% of child tennis injuries that occur in formal play and 27% that occur in informal play were the result of the child being 'hit by a tennis racquet'. These acute tennis injuries are not discussed in the literature and the mechanism of these injuries and contributory factors require more detailed investigation. To guard against racquet hits, children should be taught to stand and keep a 'safe' distance from other players. A "rule of thumb" is required to assist children to estimate the safe distance.

Recommendations for further research, development and implementation

- Players, especially those with arm and shoulder symptoms, should seek professional assistance when selecting a racquet and choosing string tension.
- More epidemiological, biomechanical and independent laboratory research is needed to determine the impact of the size, shape, frame material, string material and tension of the racquet on the incidence of upper extremity overuse injury in tennis.

8.4.2 Balls

There are two types of tennis balls, vacuum hollow-centred and the hard-core centre which may vary in terms of stiffness and elastic properties and the outer fuzz layer (nylon felt nap) (Nirschl & Sobel 1994). Regular duty balls, which have tightly woven felt, are designed for clay courts and indoor carpet (and are also suitable for grass). If used on hard courts the ball tends to play too fast because there is less felt to 'bite' the surface, and to develop worn bald spots. Extra duty balls have more felt and are designed to withstand the harder pounding the ball gets on abrasive hard-court surfaces. If used on clay, they tend to absorb moisture and grit, become heavy, play slower and lose their bounce. There are grass-specific balls on the market or players can use regular duty balls. Low-pressure or pressureless balls are designed to provide a true bounce at high altitudes (Cleary 1997). Players are advised to always use the recommended ball type, matching it with the playing surface and atmospheric conditions.

All balls used in competition must meet official specifications developed by the International Tennis Federation (ITF), which has a laboratory set up specifically for the purpose of racquet and ball analysis Tennis balls must have a diameter of 6.35-6.67cm and weigh between 56.7and 58.5 grams (Australian Sports Commission 1997). In the past, all balls used for match play were white. In 1970, however, the International Lawn Tennis Federation permitted the experimental use of coloured balls as it was thought that red or yellow might be more easily seen by players playing indoors under lights (Australian Sports Commission 1997).

The epidemiological evidence that balls are implicated in arm overuse injury is sparse. Kamien (1988) reported from his retrospective survey of 260 recreational players that 14% of the 148 players who self-reported suffering from a tennis elbow at least once in their tennis career attributed its onset to playing after rain with damp heavy tennis balls. He advises that players rehabilitating from tennis elbow should not play in wet and windy conditions (Kamien 1990). Nirschl and Sobel (1994) state that playing with wet balls and solid core balls has been observed to increase the incidence of arm symptoms among tennis players but provided no evidence to support these statements. Groppel (1992) reported that non-pressurised balls, despite their usefulness at high altitudes, are seldom used in major tournaments because skilled players find them too heavy. He observed that 'some authorities' hold the opinion (unverified by research) that the heaviness of nonpressurised balls may contribute to arm injury.

There is a general consensus in the literature that fresh balls should be used, especially by rehabilitating players recovering from an arm injury and players with a history of arm overuse injuries (Lehman 1988; Nirschl & Sobbel 1994; Field & Altcheck 1995). It should be noted that if pressurised balls are removed from their vacuum-sealed container, or the seal of the can is broken, they will gradually lose rebound after about a week and play 'dead' (Groppel 1992). Heavy, spent or 'dead' vacuum balls or worn balls require greater stroke energy to maintain comparable ball speed and the athlete's tendency to stroke these balls harder is generally believed to increase the likelihood of arm injuries (Lehman 1988; Nirschl & Sobbel 1994; Field & Altcheck 1995). Therefore, coaches should not use a basket full of 'dead' balls when doing repetitive training.

Recommendations for further research, development and implementation

- Players should always match the ball type with the playing surface and climatic conditions.
- Players with arm symptoms should avoid playing with wet balls and in windy conditions.
- Players should limit play with used balls and avoid play with dead balls.

8.4.3 Footwear and orthoses

Footwear

Correct, suitable and safe footwear is believed to play an important role in injury prevention (Cross 1993). The footwork required in tennis is unlike that in most other sports: quick starts in all directions, quick stops from all directions, jumping at different angles, landing and twisting (Groppel 1992). Tennis is played on a variety of surfaces and this must also be taken into consideration when selecting footwear.

Stanitski (1989) reports that anecdotal evidence associates ill-fitting sport shoes with foot, ankle and lower extremity complaints. In general, the tennis shoe must be designed to accommodate side as well as forward and backward motion.

Nirschl (1994) outlined the basic design features that should be incorporated into the tennis shoe:

- the outer sole must adapt well to the playing surface;
- the midsole should absorb impact forces;
- the insole should provide cushioned comfort and allow the insertion of a custom made orthotic if needed; and
- the shoe should feature a firm heel counter, adequate toe box, multiple lacing system and a flexible forefoot.

However, Kibler and Chandler (1994) observe that a number of the innovations incorporated into tennis shoe design, such as the sole cushioning system and lacing patterns, have no research basis and there is little evidence to show the superiority of one type of shoe over another. However, the authors conclude that tennis players may benefit from wearing shoes that are designed specifically for tennis.

Nigg and a team of colleagues attempted to address the lack of research on the tennis shoe by undertaking three studies to establish design criteria to reduce the load of tennis play on the human locomotor system (Nigg et al. 1989). They initially studied the different movements in tennis in a small experimental study involving 30 average and 4 advanced players. They found that tennis involves walking, running (forward) and sideslipping, sliding (on clay surfaces only), landings on the heel, ball and inner and outer edges of the foot and forward and lateral movements. The movements of advanced and average players were the same but their frequency of employment was different.

Subsequently, the team investigated the effect of the tennis shoe on the frequency of injury in two studies. First, Nigg and Denoth (1980, cited in Nigg et al. 1989) conducted a retrospective survey of 1,018 tennis players that covered the previous two to three seasons. They found that there were significantly fewer surface-related injury problems on surfaces that permitted some sliding (sand and synthetic sand) irrespective of playing time per week. They concluded that the translational frictional relationship between shoe and surface were an important consideration on surfaces that permit sliding and less important on surfaces where sliding is not possible. However, the rotational frictional relationship between shoe and surface (the resistance to the momentum of rotation) was observed to be an important consideration for all surfaces.

Second, Luethi et al. (1986, cited in Nigg et al. 1989) investigated the effect of hard and soft tennis shoes on the frequency of injury problems in a prospective study of 200 healthy subjects. The subjects were examined anthropometrically, biomechanically and medically prior to the study. Half the subjects were given a soft tennis shoe, and the other half were provided with a stiff shoe. The subjects played tennis at least twice a week for two months and reported to a physician if they suffered any injury problem (who completed a questionnaire and made a diagnosis). Thirty-nine percent of all players reported an injury, mostly to the feet. The incidence of injury for the soft shoe group was 32%, and the hard shoe group 47.1% (no test of statistical significance was reported).

An investigation of the location of injury revealed that in the soft shoe group most of the problems were in the region of the arch of the foot, whereas in the hard shoe group, the toes, ankles, and knees were mainly affected. A more detailed investigation of the biomechanics of movement in both groups revealed that, on average, the soft-shoe subjects with injuries showed more supination (inversion of the foot) than their counterparts with no injuries and the opposite was true in the hard-shoe group. This finding suggest to the authors that there is an ‘ideal’ range of supination as far as lateral movement is concerned.

From this series of studies Nigg et al. (1989) constructed a preliminary table of criteria for tennis shoe construction (Table 10). However, the authors recommended that more research is needed on: the different movements that occur during tennis; the discomfort and injuries caused by tennis shoes; and the theoretical analysis (modelling) of the forces acting on and in the locomotor system.

Table 10: Summary of the important criteria for the design of tennis shoes from a biomechanical perspective

Perspective	Significance
Supination	Very important
Cushioning – heel	Important
Cushioning – ball	Important
Rotational friction	Important
Translational friction	Important only on sand, granular surfaces etc.

Source: Nigg et al. 1989

Stussi et al. (1989) investigated potential solutions to the stress on the lateral ankle ligaments during rapid sideways movements and changes of direction in a laboratory study involving 15 athletes (including tennis players). The authors found that wearing a shoe with a higher shaft and a sole that allowed some (but not too much) sliding on fabric surfaces improved the ability of the ankle to withstand strain.

Despite the lack of published research evidence, the general consensus in the literature is that impact forces and foot pronation can be modified by a well-designed sports shoe (Cook 1990; Barnes & Smith 1994). The corollary to this view is that properly designed shoes can prevent injury. The multi-national tennis shoe manufacturers allocate large budgets to product development, in consultation with professional tennis organisations, but information to guide consumer choice of an appropriate shoe, especially for the surface/s on which they play, is not freely available. Heidt et al (1996) conducted an independent laboratory evaluation of the shoe-surface interaction in both interior translational friction and rotational torque of 15 football shoes made by three manufacturers (Apex, Nike and Reebok). Shoes tested in conditions for which they were not designed displayed excessive or extreme minimal friction characteristics which may have safety implications. The authors recommended that shoe manufacturers display suggested indications and playing surface conditions on which their shoes are or are not recommended. They also recommended that all shoe releases should be independently tested to provide to the consumer the information needed to make an informed decision.

Robbins and Gouw (1991) believe that modern athletic footwear actually makes the durable barefoot vulnerable to injury. Their laboratory research involving 20 athletes showed that 'high impact' sports footwear makes chronic overloading inevitable because the extra comfort provided by these shoes desensitises the plantar surface of the foot to the cues that trigger impact modifying behaviour in the athlete just prior to landing. The authors found there was little convincing evidence in the literature to show that currently available athletic footwear confers any injury protection benefit.

Orthoses

Tennis requires side to side or lateral movements, which place increased stress on the ankle and transverse tarsal joints. The term 'orthosis' is currently used to refer to one of a variety of devices that are used inside the shoe to provide support, increase shock absorption, or influence foot position in some way (Janisse 1994). Orthoses can be pre-made or custom-made and range from heel cushions and arch supports to full insoles. It is generally proposed that corrective biomechanical orthoses alleviate symptoms and reduce the risk of lower limb overuse injuries caused by abnormal position or functions of the joints of the lower limb and foot (Kilmartin & Wallace 1994). It is also speculated that poor foot posture may be associated with back and even shoulder pain and thus the benefits of orthoses may not be limited to the prevention of lower extremity injuries (Braybon 1995).

The use of orthoses to balance the feet in unidirectional and multidirectional sports was introduced after small imbalances were observed to affect athletes' performance and risk of injury (Subtonick 1985). Imbalances often refer to the degree to which a person pronates (the rolling in of the ankle). Whilst pronation is a necessary part of weight bearing, it is believed that excessive pronation may lead to lower limb overuse injuries.

Gross and Napoli (1993) cite a number of surveys of injured athletes (mostly runners) and healthy military recruits that consistently indicate (from self-reported data) that orthoses provided symptomatic relief from some lower extremity complaints (James et al. 1978; D'Ambrosia 1985; D'Ambrosia & Douglas 1982; Dugan & D'Ambrosia 1986; Gross et al. 1991; all cited in Gross & Napoli 1993). The authors caution that successful treatment requires careful evaluation of the player's feet and the formulation of a properly fitted orthosis.

McGrath and Finch (1996) reviewed several studies that evaluated orthoses in a number of settings related to running. As running is a key component of tennis, reference is made to these studies. The majority of studies included in the review consistently found orthoses alleviated symptoms of overuse injuries (Gross & Devlin 1991; Donateli et al. 1988; Axe & Ray, 1988; Schwellnus et al. 1990). One study—a randomised controlled trial of the effectiveness of the prophylactic use of neoprene shock absorbent insoles in the reduction of overuse injury in healthy army recruits undergoing 9-weeks basic training—found a significant reduction in overuse injuries including tibial stress syndrome (but not stress fractures) in the experimental group (Schwellnus et al. 1990). However, another controlled trial reported no significant difference in the frequency of tibial stress fractures in a group wearing viscoelastic insoles compared to those who were not (Gardner et al. 1998). Two limitations of the latter study were that the shock absorbency of the viscoelastic insole was not tested prior to the study (a later study reported that viscoelastic orthoses have poor shock absorbency) and it was not made clear whether the reported injuries were related to impact forces (McGrath & Finch 1996).

Kilmartin and Wallace (1994) reviewed the scientific basis for the use of biomechanical foot orthoses in the treatment of lower limb sports injuries and agreed that there exists a body of clinical and epidemiological evidence that supports their usefulness in relieving pain related to lower leg and foot overuse injuries. However, the authors could find no clear scientific evidence to explain how orthoses work. Orthoses have not been shown by research to have any effect on knee function. A number of studies have found that they limit rearfoot movement but the authors found that the clinical significance of excessive rearfoot movement in overuse injuries is not established. They concluded that a randomised controlled trial (in a population with no foot pain) is required to test the advantage of placing the foot in a supinated or neutral position rather than a pronated position. Such a trial would have the capacity to establish the significance of pronation in overuse injury and the clinical value of an orthosis. The authors recommend that widespread promotion of orthoses should be delayed until the usefulness of orthoses is justified by research.

In summary, despite some epidemiological evidence from retrospective and prospective observational studies that orthoses relieve and may even prevent injury, the role of malalignment in lower limb overuse injury is not established nor is the scientific basis for the treatment of overuse injury with orthoses. The hypotheses that structural abnormalities are a risk factor for overuse injuries and that these can be corrected with orthoses requires testing in well-designed controlled studies.

Socks: composition and fibre

Blistering of the feet, a response of the skin to rapidly applied shearing forces during normal running, is common among tennis players. Sequela of friction blisters can lead to compromised performance, local infection and may progress to septicemia (Richie 1993). Although ill-fitting, poorly designed or worn-out shoes are most commonly implicated in blister formation, improper or ill-fitting socks are also an important causative factor (Herring & Richie 1990). Recommendations for the prevention of blisters on the feet (based on anecdotal rather than research evidence) include wearing two pairs of socks, wearing socks composed only of cotton fibres, debridement, wearing padding and cushioned insoles, and the application of petroleum jelly, tincture of benzoin spray and tape to the feet (Herring & Richie 1990).

Richie (1993) states that a protective material must be interfaced between the foot skin and shoe to reduce potentially damaging shearing forces. A secondary factor that contributes to blistering is moisture (perspiration). A sock can reduce moisture on the surface of the skin by either absorbing or wicking moisture from the skin surface and moving the moisture through the fibre framework of the sock to the shoe upper.

Richie and colleagues conducted three studies designed to determine the effect of sock fibre composition and padding on the formation of friction blister sequelae in running athletes (Richie 1993). The first study involved 457 runners and tested seven popular brand of socks, found no difference between brands in the frequency of blistering but the severity of blistering was significantly reduced when the runners were wearing heavily padded socks. The second study was a small double-blind randomised trial involving 35 long distance runners which compared the performance of 100% cotton fibre socks with 100% acrylic socks in a patented padded construction. This trial found that the acrylic fibre socks were associated with significantly fewer and smaller blisters and less severe blisters compared to cotton fibre socks. The third study, involving 50 runners, tested generic cushioned-sole running socks and aimed to identify if acrylic or cotton socks offered superior protection against blisters. Neither the cotton nor acrylic socks were found to be superior in reducing the frequency or severity of blisters. It was concluded from these studies that acrylic fibre socks are only superior to cotton fibre socks when the fibres were arranged in dense padding under the key shearing stress areas of the foot (Richie 1993).

The limitations of this series of studies were outlined by McGrath and Finch (1996). Except for the first study, they involved relatively small samples of runners who may not be representative of the running population as a whole or the athletic population in general. Also, as acknowledged by the researchers, no attempt was made to control for other factors that contribute to blister formation: the runners' personal training habits, running regime or running surface; shoe fit and the condition (although proper fit and condition were confirmed at the time of sock assignment); ambient and running surface temperature; and intrinsic structural or mechanical problems in the feet of runners. Whether attempts were made to replicate these results was also not made clear in the research report. McGrath and Finch (1996) conclude that the findings reported from the studies by Richie and colleagues should be treated with caution.

The shoe itself, the player's footcare and hygiene routine and callous formation are important factors to be addressed in blister prevention and management. Biomechanical factors may also be implicated and orthoses may be helpful if the cause is mechanical. (Personal communication, Kathy Martin, Sport Medicine Consultant, Tennis Australia)

Recommendations for further research, development and implementation

- Players should choose their shoes carefully, preferably with professional advice on the most appropriate shoe for their foot type and the playing surface on which they mostly play.
- Tennis shoe manufacturers should provide more information to consumers at point-of-sale on suggested indications and playing surfaces for which their shoes are or are not recommended.
- Future research on tennis footwear must adjust for confounding factors, such as previous injury and exposure, when investigating the relationship between shoe construction and injury.

- The effectiveness of orthoses in the prevention and treatment of overuse injury should be determined by well-designed controlled studies that involve sufficient subjects to provide definitive results.
- Further research is needed to evaluate the protection against foot blisters afforded by the different kinds of tennis socks with the aim of developing design and material criteria.

8.5 PROTECTIVE EQUIPMENT

The only item of protective equipment that has been considered for tennis is protective eyewear, although braces and foot orthoses (discussed above) could be regarded as protective equipment.

8.5.1 Protective eyewear

As discussed in section 6.4.2, tennis eye injuries account for between 7-11% of all sports-related eye injuries but there is little detailed information on the nature and severity of these injuries (Fong 1994; Jones 1988; Gregory 1986; Larrison et al. 1990). It is believed that most eye injuries in tennis players are racquet and ball-related. There were 58 cases of tennis-related eye injury treated at the Royal Victorian Eye and Ear Hospital in the two-year period between November 1989 and October 1991, 16 (28%) of which required hospital admission (Fong 1994).

Protective eyewear has been developed for other racquet sports where there is a high risk of ball-related eye injury, for example, squash. Easterbrook (1988) reported that no significant eye injury has been reported in a squash or racquetball player wearing Canadian Standards Association-approved eyeguards or eyeguards that meet American Standard of Testing and Materials (ASTM) 1985 or 1986 standards up to the date of publication of his article (1988). However, the tennis ball is larger than either the squash ball or badminton shuttlecock and does not fit as easily into the eye orbit (the bone cavity containing the eyeball and surrounds). More needs to be known about the frequency, nature, severity and mechanisms of eye injuries in tennis before consideration is given to protective eyewear for tennis.

Recommendations for further research, development and implementation

- Update epidemiological research into the incidence and nature of eye, facial and dental injuries in tennis and investigate risk factors and potential protective measures.

8.6 MODIFIED GAMES AND AGE RESTRICTIONS IN ELITE COMPETITORS

8.6.1 Modified games

Children who play sport should not be thought of as ‘little adults’. Significant differences exist between child and adult athletes, and those interested in injury prevention must understand these differences (Meyers 1993). Even within the same age groups, physical maturity may vary greatly (Welford 1989). Growth and maturation rates demonstrate marked variability as do concomitant gains in co-ordination and strength, flexibility and endurance (Stanitski 1989). Physical maturity is believed to exert a greater influence on injury risk than chronological age (Backx 1991).

Young tennis players generally perform ‘less than smooth’ strokes and often use incorrect stroke techniques. They may also be playing with an inappropriately racquet in terms of size and weight. The impact forces, repetition of play and the softer joints and developing bones of children, increases their risk of injury (Harding 1991). Correct technique, conditioning of muscles, avoiding overuse and selecting an appropriate racquet may assist young players to avoid injury (Harding 1991).

Tennis Australia/Victoria organise a number of programs that aim to increase participation and skill levels in young players. 'Ace tennis' is aimed at children 5-12 years of age. The game uses modified racquets and is played on the four service courts of any tennis court. *Tennis Australia/Victoria* also offers programs through school, as well as 'kids karnivals' and national tennis fun days. Table 11 outlines the programs available for the various age groups of children and the game modifications entailed.

Table 11: Progression from modified to regulation games for younger players

Age	Game	Equipment	Rules	Court Size
6-7	Ace Tennis Stage 1 Skills	Plastic/wooden bats; foam ball	Children's own	Over any obstacle eg. a line, and small space 4m x 6m
8-10	Ace Tennis Stage 2 Skills/Game	Plastic/wooden bats or sub-junior strung racquet; foam ball or depressurised ball	First to 11 or 15 (table tennis rules)	Small. Approx. 6m x 10m with a net height between 762mm and 800mm
9-11	Modified Tennis – singles court only	Junior strung racquet; depressurised ball	Tennis	Four children play in the singles court. The server can serve underarm or overarm from anywhere between the service line and baseline
9-12	Tennis	Junior of full sized racquet; depressurised or proper tennis ball	Tennis	Full court
12+	Tennis	Junior or full sized racquet; proper tennis ball	Tennis	Full court

Source: Aussie Sport, Australian Sports Commission, 1991

Finally, children should equate sport with enjoyment, without any fear of getting hurt (Kennedy & Fitzgerald undated). Therefore, safety rules and adequate training are required and graduated progression from modified to regulation tennis is highly recommended.

8.6.2 Age restrictions for elite competitors

At the elite level in women's tennis, the WTA TOUR has introduced an Age Eligibility Rule which restricts a 14 year-old player to up to 5 professional events (but she is not allowed to compete in WTA TOUR and/or Grand Slam events) and then progressively increases the number of professional events allowed until the player is aged 18, when she is able to compete in an unlimited number of events. This rule was introduced to protect very young players from the rigours of competing in women's professional tennis and co-exists with a number of support programs for professional players under the WTA TOUR Player Development Program. (Personal communication, Kathy Martin, Sports Medicine Consultant, Tennis Australia)

Recommendations for further research, development and implementation

- Children should be progressively introduced to tennis through the modified games program promoted by Tennis Australia and Tennis Victoria.
- Children should play tennis with an appropriate racquet, in terms of size and weight.
- As children progress from modified games to regular tennis, guidance should be sought from an accredited coach on a suitable training routine.

8.7 EDUCATION AND COACHING

Coaches are responsible for the design of safe and effective training programs. All coaches should be educated in the general principles of sport and fitness and understand tennis and its potential risks (Weaver et al. 1996). As much as possible, coaches should prevent players from attempting skill or competition levels for which their maturity, strength or other attributes are insufficient. A coach should be an educator, psychologist, injury prevention and first aid person and a role model.

It is important that coaches undertake regular training to update their knowledge of injury prevention, first aid, basic life support and rehabilitation principles and are kept informed on developments in knowledge about training children in tennis skills (Weaver 1996). Tennis coaches can undergo a variety of training at various levels. These range from Level 0 course, as a base, to elite level coaching courses. The intensity and educational expectations increase with the level of the course. Clubs and associations should encourage and support coaches to become accredited and continuously upgrade their knowledge and skills.

Sports trainers are also essential to the prevention of tennis injury and also need to be well-qualified to deal knowledgeably and efficiently with the prevention, treatment and rehabilitation of injury. The Australian Sports Commission (1997) indicates that education lies not only with coaches, officials and trainers but also with administrators and facility managers/operators who are often in charge of the overall risk management of the sport.

Recommendations for further research, development and implementation

- Accredited coaches should be available at every club to advise and monitor the skills development of players at every level (competitive and social).
- All coaches should be accredited and undergo the regular training and re-accreditation provided through Tennis Coaches Australia and state divisions.
- Continuous systematic evaluation of the effectiveness of education/training programs should be maintained.

8.8 TREATMENT AND REHABILITATION

Despite the best preventive measures, there is always the chance of injury among tennis participants. Many injuries are re-injuries or aggravations of existing injury. Therefore, proper treatment and management of a new injury is especially important. Treatment may include first aid, rehabilitation and taping and bracing of the injured body part. Treatment and rehabilitation should aim to return injured players to, at least, their previous level of performance and protect them from further injury.

The causes of tennis injuries are diverse and may be multifactorial so a combination of procedures may need to be administered to prevent recurrence. Overall, the treatment goals are pain relief, promotion of healing, decreased inflammation, and a return to functional and sports activities as soon as possible (National Sports' Trainers Scheme 1994).

8.8.1 Sports first aid

The provision of accessible and appropriate sports first-aid is an important injury countermeasure. The initial treatment provided to the injured person is a crucial determinant of the rate and likelihood of recovery and return to play and usually involves following the well-recognised regime of rest, ice, compression, elevation and referral (RICER) (Knight 1985; Larkins 1990). This procedure is widely promoted and used by sports medicine practitioners but there are no recent studies on its effectiveness.

Sports First Aiders' and Trainers' courses are targeted to school teachers, coaches, parents, club officials, athletes or anyone interested in providing a valuable, often voluntary, contribution to sport (Australian Sports Commission 1997). Sports Medicine Australia (SMA) organises a number of sports first aid courses at various levels and intensities. The SMA 'Sports First Aid Course' advises on the RICER technique and proposes that it reduces the severity of injury, haematoma and swelling; limits tissue damage; and lessens recovery time (National Sports Trainers Scheme 1994).

In addition to RICER, NO 'HARM' is also advocated for the treatment of injury: no Heat, no Alcohol, no Running and no Massage during the first 48-72 hours after an injury. After the initial period of icing, alternate hot and cold bathing is recommended to decrease bleeding and swelling (3 minutes of each repeated 3 times, once a day). Massage is also believed to aid rehabilitation, but it is recommended that massage should not be done within 72 hours of the time of injury (Cook,1989). *The Orientation to Coaching Manual* provides instruction on the treatment of minor injuries (Tennis Australia, 1996). Consultation with a medical practitioner or a sports medicine specialist may also be required and further treatment and/or rehabilitation prescribed.

First aid or medical assistance should be available at all tennis matches, not only at tournaments and elite level events. The latter may include the attendance of sports trainers, physiotherapists and/or doctors at large scale or elite competitive events. However, at the local club level, medical assistance is often left to parents or club associates who may not have sports medicine or first aid training. It is the responsibility of clubs and associations to ensure that qualified first-aiders are available at all levels of competition and at informal club events.

8.8.2 Taping and bracing

Over the last decade there has been an increase in the use of taping and bracing to both prevent injury and allow an earlier return to play after injury. Taping and bracing helps to reduce the range of movement possible at the protected joint and is therefore believed to reduce the risk of injury or its severity (National Sports Trainers Scheme 1994).

In tennis, a range of body sites may be taped or braced to aid rehabilitation or, less commonly, to prevent injury or re-injury by prophylactic use. Most studies on the effectiveness of taping and bracing have not specifically involved tennis players, however the results are relevant and are presented here.

Ankle taping and bracing

Ankle inversion sprain is one of the most common injuries in sports that involve running, sudden change of directions or landing from a jump. Ankle taping and bracing are generally considered to be components of the management and rehabilitation process for ankle ligament injuries but prophylactic (preventive) taping and bracing is becoming more common in sports that have high rates of ankle inversion injury, such as netball, basketball and soccer.

However, the research evidence is inconclusive on whether taping and bracing have a protective effect (Sitler & Horodyski 1995; Hume & Gerrard 1998; Robbins & Waked 1998). Hume and Gerrard (1998) recently reviewed research studies on the effectiveness of external ankle support. The authors concluded that several epidemiological studies indicate that taping and bracing may be effective in reducing the frequency of ankle inversion injuries, particularly among athletes with previous ankle injury but, overall, the evidence of a uniform protective effect remains equivocal.

Studies in the review that showed that ankle taping is protective against ankle re-injury include: an early randomised controlled study of 2,562 US intramural university basketball players by Garrick and Requa (1973) conducted prospectively over two seasons (although the number of injured players in the study groups was small); and a retrospective study covering six seasons of collegiate football practices and games in the US conducted by Rovere, Clarke and Yates (1988). The design of the latter study was weakened by a lack of a comparison group with unsupported ankles and the non-randomised assignment of ankle supports (tape and braces). The disadvantages of taping include the expense, inconvenience and the diminution of support for the ankle after 10-40 minutes of active participation (depending on the vigour of play).

Hume and Gerrard (1998) reported that several controlled studies have shown that ankle braces protect against ankle re-injury. The strongest study, a large prospective randomised controlled trial on the effectiveness of a semi-rigid ankle stabilisers (involving 1,601 healthy US Military Academy cadets playing basketball) was conducted over two seasons by Sitler et al (1994). The study found that semi-rigid ankle stabilisers significantly reduced the frequency, but not the severity, of acute ankle injuries in both the non-injured ankle group and previously injured ankle group. It is not clear whether the results from this well-designed study are generalisable because army cadets may be different from civilian populations of basketballers.

A prospective study in soccer players by Troop et al. (1985) and a randomised controlled trial in soccer players by Surve et al. (1994) also report that ankle orthosis (braces) when used by players with previous ankle injury protect against re-injury. The latter study, which involved 258 senior soccer players with previously injured ankles and 246 uninjured players, trialled the effectiveness of a particular brand of semi-rigid orthosis and found a fivefold reduction in the incidence of recurrent ankle sprains in soccer players using the orthosis but no significant reduction of ankle sprains in previously uninjured ankles.

The studies outlined above consistently show that the effectiveness of the external ankle support is dependent on the material properties and application method of the tape or brace and the innate stability and previous injury status of the athlete's ankle (Hume & Gerrard 1998). Also, players with previous ankle injury were shown to be more at risk of re-injury than players with no prior history of ankle injury irrespective of whether they taped and/or braced their vulnerable ankle/s (Hume & Gerrard 1998). The cause and effect association between bracing and reduced ankle injury needs to be replicated over time in different study populations before it is convincingly established.

Of note is a contrary view on the value of taping and bracing put forward in a recent review by Robbins and Waked (1998). On the basis of published studies on barefoot and shod subjects and physiological evidence, the authors contend that ankle injuries are not caused by any innate structural weakness in the ankle but by decreased foot position awareness (proprioception) caused by sports footwear. They theorise that if taping and bracing devices do protect the ankle (and they are not convinced by current evidence) it is because they restore tactile cues on the plantar surface of the foot by increasing skin pressure (through taping) or skin traction (through bracing). This enables shod players to better 'sense' correct foot position and orientation before making full contact with playing surfaces. The authors recommend taping over bracing because of the research that shows taping interferes least with normal movements, but they contend that the best solution to ankle inversions is thinner and firmer soled sports footwear that heighten the wearer's awareness of foot position.

On the weight of current epidemiological evidence it would appear that tennis players who have a history of ankle sprain injuries should seek a sports medicine professional's advice on a suitable ankle support in the form of a semi-rigid orthoses or air cast brace. The benefit of the prophylactic use of ankle taping and bracing by players with healthy ankles is less well established.

Forearm (counterforce elbow) braces

Applying a firm constraint around the forearm to alleviate tennis elbow was first suggested by Morris in 1882 and has been noted clinically to minimise symptoms of lateral and medial tennis elbow since that date (Kamien 1990; Harvey et al. 1990; Nirschl 1988 & 1992; Rettig 1998). The theory is that a clasp band applied firmly on the upper forehand (note there are now several types) produces a counterforce which prevents the forearm muscle from full expansion, thus dampening the force on their tendinous insertions while maintaining essentially normal arm function and muscle balance. There is some scientific evidence to support this effect. Using sophisticated electromyographic techniques and 3-dimensional cinematography, Groppel and Nirschl (1986) reported that the counterforce brace produced lower muscular activity in the extensor muscles during the serve and one-handed backhand and decreased the angular acceleration of the elbow and wrist during the serve, and the elbow during the backhand. The study involved braced and unbraced asymptomatic tennis players of varying skill levels.

While there is some epidemiological and anecdotal clinical evidence to suggest that bracing may be beneficial, the efficacy of the counterforce elbow brace has not been tested in randomised controlled trials. Two retrospective surveys of players conducted in the 1970s (Nirschl 1974; Priest et al. 1980; cited in Kamien, 1990) and a later retrospective study of club-level players by Kamien (1988), reported that 75-89% of players with a history of tennis elbow found bracing helpful in alleviating elbow symptoms. There were no details given of the type of brace, the positioning, wearing regime or use of concurrent treatments. By contrast, an early Canadian survey of 500 players by Gruchow & Pelletier (1979) reported that the forearm brace was the least successful of all the treatments tried by respondents with a history of tennis elbow.

Although clinical experience and epidemiological evidence indicate that the use of an elbow brace may be a valuable complementary tool in the treatment of tennis elbow, more controlled research is required to definitively establish the protective and rehabilitative effects of counterforce bracing.

8.8.3 Rehabilitation

Rehabilitation of an injured athlete should restrict the athlete from re-starting activities too soon (Van Mechelen 1992). A rehabilitation program cannot be regarded as complete until the athlete is free from pain, muscle strength has returned to about the pre-injury level, and articulatory mobility (joint union movement) has recovered to pre-injury level.

Rehabilitation may mean complete cessation of tennis play for a given period or a reduction in training. It is generally recommended that ‘range of motion’ exercises are beneficial during the acute phase of an injury to reduce swelling and maintain joint mobility during rehabilitation. This should be done within the confines of a compression dressing such as athletic tape or elastic bandages to protect the injured area without restricting active movement (Hess et al. 1989). Other rehabilitation measures include the application of a contrast program of heat and cold and massage. Tennis players should also undergo appropriate fitness testing prior to return to full play after injury. There is a lack of knowledge on optimal rehabilitation regimes, especially for tennis elbow and tennis leg (personal communication, Max Kamien, University of Western Australia).

Recommendations for further research, development and implementation

- Event organisers and tennis clubs should ensure that there are qualified first aid personnel/sports trainers at all events and competition match days.
- Clubs should have a well-stocked first aid kit and a supply of ice-packs.

- Players should seek prompt attention for injuries from a sports medicine practitioner and allow enough time for adequate rehabilitation before returning to their pre-injury level of activity.
- Players with recurrent injuries should seek expert advice on appropriate taping or bracing and rehabilitation.
- Further research and evaluation of rehabilitation programs is required, to develop optimal regimes.
- Further controlled research is needed to investigate the efficacy of prophylactic taping and bracing in the prevention of ligament injury and re-injury in tennis.

9 SUMMARY AND CONCLUSIONS

This report has presented hospital emergency department data on tennis injury and assessed the full range of injury prevention strategies and countermeasures. Recommendations for further research, development and implementation are based on the review of the literature as well as discussions with the experts acknowledged in this report.

The effectiveness of many of the available countermeasures have not been proven and more controlled studies "in the field" are needed. For example, the evidence for the effectiveness of certain countermeasures such as warming-up, improvements in shoe design and ankle and elbow taping and bracing remains equivocal. More effort should be directed to basic scientific studies to better understand the biomechanics of tennis so the mechanisms of injury are better understood.

In addition to the specific recommendations in this report, the following set of more general recommendations are made:

- Improve data collection on the frequency, pattern and contributory factors to tennis injury. All data collections should conform to national guidelines for sports injury surveillance (the Australian Sports Injury Data Dictionary).
- Further epidemiological research is needed to determine the risk factors for tennis injury and to evaluate the effectiveness of countermeasures.
- Guidelines for minimum safety requirements for organised tennis (including the need for mobile phones, emergency telephone contacts and first aid kits) should be developed and widely disseminated.
- A cost of sports injury study is required to determine the overall cost of sports injury and the relative cost of injuries for different sports.

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APPENDIX 1

COMPARISON OF STUDY FINDINGS ON FREQUENCY OF INJURY BY BODY SITE INJURED

Author	Cunningham & Cunningham, 1996	Hutchinson et al., 1995	Reece et al., 1989	Baxter-Jones et al., 1993	Kibler et al., 1988	Winge et al., 1989	Chard & Lachman, 1987	Kamien, 1989	NSW Youth Sport Report, 1997
Data source	1994 Australian University Games (Injury Surveillance)	US Tennis Association National Boys' Tennis Champ -ionship (Injury Surveillance)	Elite young players at the AIS. (Retrospective analysis)	Young elite athletes (case study)	Elite juniors	Elite tennis players (prospective injury registration)	Sports injury clinic presentations (retrospective case study)	Tennis club players (retrospective case study)	NSW youth (retrospective) (proportion %)
Sample size	173	1440	45	156	97	104	131	260	251
Period	6 days	6 years	4 years	2 years	2 years	1 season	8 years	1 year	
Injury (%)	7%	21%		52%/2 years	65%/2 years			48%/1 year	
BODY SITE INJURED									
Head/face		4% (neck)					2%		7% (neck)
Upper extremities		26%	20%		35%	46%	35%		
Arm						7%			
Hand/finger						11%			10%
Wrist					9%				
Shoulder					22%	17%			19%
Elbow					8%	11%			
Lower extremities		49%	59%		54%	40%	45%		
Foot					9%	9%			8%
Knee					18%	7%			26%
Lower leg					12%	9%			8%
Ankle					13%	11%			33%
Upper leg						4%			10%
Back		16%			11%	11%			9%
Trunk		5%	21%				20%		
Other						3%			
TOTAL		100%	100%		100%	100%	100%		

APPENDIX 1 (cont'd)

COMPARISON OF STUDY FINDINGS ON FREQUENCY OF INJURY BY INJURY TYPE

Author	Cunningham & Cunningham, 1996	Hutchinson et al., 1995	Kibler et al., 1988	Winge et al., 1989	NSW Youth Sports Report
Data source	1994 Australian University Games (Injury Surveillance)	US Tennis Association National Boys' Tennis Championship (Injury Surveillance)	Elite juniors (pattern of pathophysiology)	Elite tennis players (prospective injury registration) (pattern of pathophysiology)	NSW youth (retrospective) (proportion %)
N	173	1440	97	104	251
Period	6 days	6 years	2 years	Outdoor season	
Type of injury					
-sprain	40%	58%	65%	17%	
- strain	13%	13%	25%	14%	73%
- contusion		7%			
- dislocation/ subluxation		1%			8%
- inflammation		1%			17%
- fracture			12%	2%	4%
- wound		12%			10%
- bursitis/ tendinitis					2%
- concussion					
- other	33%	7%			
- overuse			63%	67%	
- blisters	13%			5%	24%

APPENDIX 2

DETAILED DISCUSSION OF TREATMENT AND REHABILITION OF TENNIS ELBOW

Non-operative treatment

'Tennis elbow' is mostly a self-limiting condition. It usually resolves spontaneously, particularly if the affected arm is rested for several weeks. There is no agreement on the most effective treatment of persistent cases (Olivierre & Nirschl 1996; Renstrom 1995; Kamien 1990).

According to Kamien (1990) rational treatment of the condition is hampered by:

- the complex nature of the condition (which may be due to a number of different types of injury that involve any structure around the elbow joint);
- the fact that most cases reported in the literature are due to repetitive occupational injury, rather than tennis; and
- the lack of controlled studies (case-control and randomised controlled trials) on the various treatments.

A planned quantitative meta-analysis of the scientific evidence on the treatment of 'tennis elbow' (lateral epicondylitis) was abandoned by Labelle et al. (1992). The authors found that only a small minority of the published studies were good quality controlled studies and the marked variation in treatment type, selection criteria and measures of efficacy forestalled the aggregation of data. A Cochrane Collaboration evaluation of treatments for tennis elbow will be published early in 1999.

Labelle et al. (1992) reviewed 185 articles published on tennis elbow between 1966 through 1990. Eighteen of the 78 papers that discussed over 40 different treatments were about a therapeutic trial with a concurrent control group. They graded these studies for criteria that should be met by a well-designed randomised controlled trial using a scoring system developed by Chalmers et al. (1981). Only one study on treatment by ultrasound (Stratford et al. 1989) met the minimum acceptable score (70%) for good quality design. The authors' general conclusion was that there was insufficient scientific evidence to support any of the current methods of treatment for acute lateral epicondylitis. They called for large, well-designed controlled clinical trials that use double blind methods (where both the observer and the subjects are blind to whether the subjects are in the treatment or control group) wherever possible.

Labelle et al. (1992) then grouped the 18 controlled studies for qualitative, rather than quantitative, analysis. On the basis of current research evidence they made the following assessments:

- Ultrasound may have a therapeutic effect, but it is unclear whether this effect is superior to that of placebo (the quality scores of the four trials in the group were 30%, 38%, 44% and 73%).

  [A later meta-analysis of the research evidence on the effectiveness of ultrasound in the treatment of pain from musculoskeletal disorders (including lateral epicondylitis) by Gam and Johannsen (1995) concluded that there was no firm evidence from well-designed controlled trials that pain relief can be achieved by any ultrasound treatment methods.]

- Ionisation, of itself, has little therapeutic effect and ionisation with non-steroidal anti-inflammatory may work systemically rather than through a local effect (the quality scores of three trials in the group were 27%, 45% and 56%).

- The therapeutic value of oral non-steroid anti-inflammatory drugs (NSAID) is unknown because there was no placebo-controlled trial among the three studies of NSAID treatments (the quality scores of three trials in the group were 11%, 27% and 44%).

  [A more recent randomised double-blind placebo-controlled trial to evaluate the effectiveness of an oral NSAID drug (diclofenac sodium) by Labelle and Guibert (1997) concluded that it was difficult to recommend the use of diclofenac in the treatment of lateral epicondylitis, even though it gave significant pain relief. There was limited grip strength and functional improvement in the diclofenec-treatment group over rest and cast immobilization (used in both treatment and control groups) and significantly more adverse events - diarrhoea and abdominal pain - in the diclofenac-treated group.]

- Steroid injection may have a positive effect but the trials in this group were generally of poor quality and some conflicting results were reported (the quality scores of five trials in the group ranged from 6% to 26%).

- The three remaining studies on infrequently implemented treatments found: no difference between treatments using physical manipulation with or without forearm straps and/or anti-inflammatory topical creams – all groups showed similar improvement (quality score 19%); no difference between the two groups comparing the use of topical dimethyl sulphoxide with a placebo – both groups improved (quality score 41%); and no difference between the two groups comparing electromagnetic fields with a placebo – both groups improved significantly (quality score 61%).

Based on their clinical experience and research knowledge, Olivierre and Nirschl (1996), Renstrom (1995) and Kamien (1990) advise that the treatment of inflammation should follow the principles of PRICEMM (protection, rest, ice, compression, elevation, medication and modalities). With some minor variations these authors recommend:

- the application of ice packs (cryotherapy) for as long as possible over the first 24 hours to relieve inflammation;
- gentle active motion rather than absolute rest/immobilisation, if comfort allows; taking of aspirin or non-steroidal anti-inflammatory drugs with caution (because of gastric side effects); and

- the application of heat and massage after acute inflammation has decreased (more for their soothing qualities than curative effect).

Kamien (1990) describes rest, sufficient to alleviate most pain and allow healing, as the cornerstone of treatment. A number of clinicians give qualified support for the use of steroidal injections (cortisone) to relieve persistent symptoms after trauma, provided they are used judiciously (Kamona 1990; Olivierre & Nirschl 1996; Wadsworth 1987; Leach & Miller 1987). Field and Altcheck (1995) report that they use steroids only rarely and generally reserve them for non-competitive athletes in acute pain who have difficulty performing activities of daily living. Because of the adverse effects of cortisone (subdermal atrophy) it is generally advised that no more than three injections are given at intervals no more than three months apart (Olivierre & Nirschl 1996; Field & Altcheck 1995). Kamien (1990) found no conclusive evidence that cortisone was more effective than more conservative (less invasive) therapies but stated that there was clear research evidence that if the patient is going to respond to cortisone he needs no more than two injections.

Other modalities described by Olivierre and Nirschl (1996) as the 'most useful' in the treatment of tennis elbow are ultrasound and high voltage electrical stimulation. They were subsequently criticised by Stalker (1998) for failing to make reference to the previously published adverse review of these treatments by Labelle et al. (1992) and the adverse findings on the effectiveness of ultrasound by Gam and Johannsen (1995).

Kamien (1990) reported that his literature search found only one case control study on the effectiveness of acupuncture. This early study (Brattberg 1983) found acupuncture treatment was completely effective in 62% of resistant cases and significantly more effective than steroid therapy (cortisone). No patients in the acupuncture treatment reported adverse effects. Renstrom (1995) cited later double blind studies by Haker (1991) that found that acupuncture was the 'method of choice in the treatment for lateral *p.170*). Kamien (1990) is sanguine about patients with recalcitrant tennis elbow turning to any of the range of less conventional methods that have reported some success (laser-acupuncture in combination, chiropractic, vitamins B or C, electrogalvanic stimulation, transcutaneous stimulators etc.) provided they are non-invasive and do not result in any treatment-related morbidity.

Rehabilitation

It is generally recommended that patients undertake a supervised, progressive and controlled program of isometric exercise (static muscle contraction) without a load and isotonic exercise (muscle movement performed at a constant level of muscular tension) after all the initial symptoms of inflammation have subsided (Olivierre & Nirschl 1996; Renstrom 1995; Kamien 1990). The aim is to restore the strength, flexibility and function of the muscles around the elbow to their pre-injury state and recondition the muscles of the forearm and shoulder before graduated return to play (Olivierre & Nirschl 1996; Renstrom 1995; Kamien, 1990). Kamien (1990) reported from his own research and two earlier epidemiological studies that 48-89% of patients self-report that exercise aided their recovery (Kamien 1988; Gruchow & Pelletier 1979 and Priest et al. 1980, both cited in Kamien 1990).

Attention to correcting faults in playing technique (especially the serve and backhand strokes) and to the type, weight, balance, string tension and grip size of the player's racquet are also recommended components of the rehabilitation process (Renstrom 1995; Kamien

1990). However, both Renstrom (1995) and Kamien (1990) report conflict in the literature regarding the association of racquet materials, weight and stiffness with the occurrence of tennis elbow.

The healing time can be long. Tennis elbow may cause pain for 1 to 72 weeks with a mean of about 36 weeks (Renstrom 1995; Kamien 1990). Because of the long treatment time and limited treatment alternatives, persistent elbow problems are frustrating for both the patient and the doctor (Renstrom 1995). The natural history of the condition is favourable to eventual recovery, without recourse to surgery, in over 90% of players who sustain an episode of tennis elbow (Kamien 1990; Renstrom 1995; Noteboom et al. 1994).

Manipulation, operative treatment and rehabilitation after surgery

Manipulation

Surgery is consistently viewed by clinicians as the therapy of last resort employed, as a general rule, only if failed healing is evident after 12 months of treatment and quality rehabilitation. Failed healing is signified by persistent pain even at rest, weakness and non-acceptable behavioural modification (Olivierre & Nirschl 1996; Renstrom 1995; Kamien 1990; Field & Altchek 1995). Because there is a risk of failure in operative treatment, Wadsworth (1982) recommends that the Mill's manipulation technique —the rapid and forceful movement of the elbow from a position of full flexion to full extension which produces an audible snap— is tried as the penultimate therapy for persistent 'tennis elbow'. He reports that the manipulation, performed with the patient fully relaxed under general anaethesia, had successfully 'cured' most of the 100 resistant cases of tennis elbow he had treated over a 20-year period (immediate cure in the vicinity of 65% and delayed cure in a further 17%). He theorised that the manipulation works by breaking down the adhesions that have formed at the common extensor origin on the lateral humeral epicondyle, hence the snapping sound.

Surgery

Kamien (1990) emphasises that tennis elbow is almost always self limiting and recommended surgery in only two circumstances: 12 months of failed conservative therapy with a level of pain that limits activities of daily living; or 6 months of unsuccessful conservative therapy in a 'well-balanced' patient who is pessimistic about the ultimate outcome of further conservative therapy.

Both open and closed surgery to relieve tension on the origin of the common extensor muscles, especially extensor carpi radialis brevis, by excising pathological tissue are practised and there are at least four different open operations of varying complexity (Kamien 1990). The proponents of the various techniques advocate them on the basis of different views on the causes of the condition (Noteboom et al., 1994).

Kamien (1990) compared ten studies published between 1973 and 1985 that reported the outcome of various surgical interventions. He found that the studies on the open operations (that require general anaesthetic or an intravenous infusion of local anaesthetic) reported success rates of 73-93% and the studies on the closed procedure, percutaneous fasciotomy, reported success rates of 70-90%. Because of the similarity in outcome and patients' preference for non-hospitilisation, the author recommended the simpler closed procedure should be the preferred option because it can be performed in the surgeon's office with the use of local anaesthesia. However, he noted that surgeons were usually antipathetic towards 'blind' operations and that open surgery allowed for greater exploration of the elbow and radiohumeral joint for pathological conditions.

Rehabilitation after surgery

The elbow is protected in an immobiliser for approximately one week after surgery and gentle active range of motion exercises are begun in the second week. The post-operative rehabilitation program is the same as that for non-surgical care of tennis elbow. Return to full elbow strength is gradual and patients are advised to wait for 6 months after surgery before returning to full tennis participation (Olivierre & Nirschl 1996). Kamien (1990) reported that, although there is some contrary evidence, a number of studies have supported the proposition that the forearm counterforce brace is an effective adjunct to therapy. Epidemiological studies by Nirschl (1974), Gruchow and Pelletier (1979), Priest et al. (1980) and Kamien (1988) found bracing to be helpful in relieving pain in 75-89% of players, based on player self-reports. The forearm counterforce brace has been shown, via electromyography and 3-dimensional cinematography, to reduce stress on the elbow joint. It produces lower muscular activity in the extensor muscles (when serving and playing backhand strokes) and reduces angular acceleration at the elbow (when playing backhand and forearm strokes) (Groppel & Nirschl 1986).

APPENDIX 3

HEAT DISORDERS

DISORDER	SYMPTOM	TREATMENT
Heat cramps	Gastrocnemius spasm (60%) Thigh spasm (30%) Other muscle spasm (10%)	Rest Ice packs on muscle Application of pressure to muscle Water replacement
Heat syncope	Weakness Tiredness Dizziness Faintness Weak, rapid pulse Decreased blood pressure	Cessation of activity Removal from direct sunlight Application of iced towels Water replacement
Heat exhaustion	Extreme weakness Exhaustion Normal or slightly elevated body temperature Thirst Oliguria Giddiness (often euphoria) Delirium Sometimes unconsciousness Profound sweating	Cooling of body Fluid replacement with cool or cold liquids Electrolyte replacement Hospitalisation if unconscious or vomiting
Heat stroke	Faintness Dizziness Staggering Headache Nausea Confusion or unconsciousness High body temperature Strong, rapid pulse Hot, dry skin	Rapid cooling of body with ice packs, ice towels, cold tub Hospitalisation Rapid fluid replacement Observation for coagulation defects