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BOWLING CRICKET INJURIES OVER: A REVIEW OF THE LITERATURE

by

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Abstract:

In Australian, cricket is the most popular sport, as in many other Commonwealth countries. The pace of cricket, hazards of the play and expectations of the players have all increased over time. Although strictly a non-contact sport, injuries in cricket can result in a number of ways. A direct blow from a cricket ball during delivery or fielding may result in fractures, bruising, or worse, while a fielder may fall or collide with a boundary fence. Cricketers can also suffer from a range of overuse injuries associated with all aspects of the game including running, throwing, batting and bowling, the latter being the most common. Training, technique, footwear, surface, rehabilitation, warm-up and conditioning are all factors contributing to overuse injuries. The range of countermeasures for preventing cricket injuries is presented in this report, together with an assessment of the extent to which they have been formally demonstrated to be effective. Such countermeasures include pre-season conditioning, pre-participation screening, protective equipment including helmets and visors, warm-up programs, attention to environmental conditions, adequate footwear, modified rules, education and coaching, first aid and rehabilitation. Players are recommended to wear an array of protective gear such as pads, gloves and boxes, to guard themselves from injury. Recommendations include the need to conduct more biomechanical and epidemiological research into the mechanisms of injury; further development and testing of protective equipment; improving education for both players and coaches, particularly at the wider community level; adopting modified rules for children; extending pre-participation screening to the general cricket community; receiving prompt first aid; and improved injury data collections, particularly for the less formal level of play.

Key Words:	Disclaimer:
cricket, bowling, injury prevention, overuse, collisions, countermeasures, evaluation	This report is disseminated in the interests of information exchange. The views expressed are those of the authors, and not necessarily those of Monash University.

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EXECUTIVE SUMMARY

Cricket has been a part of Australian history since colonisation, with international games first taking place in 1861. The pace of the game, hazards of the play and expectations of the players have all increased over time.

Cricket injuries can be recalled as far back as 1751 when Frederick, the Prince of Wales who greatly enjoyed the game of cricket, was killed by a strike with a cricket ball. Despite the historical recognition of injury and possible death resulting from cricket, few well conducted studies have documented the incidence and nature of cricket injuries during a season, particularly at the less formal levels of play.

Cricket injuries amongst adults (>15 years) who presented to emergency departments in Australia, accounted for 7.3% of all sporting injury cases. This ranks cricket injuries the fifth greatest source of sports-related emergency department presentations. Child cricket injuries contributed to 3.7% of all sports-related injuries, ranking it the eighth most common cause of sports-related injury.

Although strictly a non-contact sport, injuries in cricket can result in a number of ways. Collision type injuries are the most common injuries during informal cricket activities. These include hits by the ball or bat, or collisions with the game surrounds (e.g. boundary fence) or other players. Protective equipment and game rules have largely developed to prevent these injuries. At the more formal level, overuse injuries are more common and attention to technique is an important countermeasure. Probably the most common of injuries, particularly during formal participation, are overuse injuries to the back associated with fast bowling at the elite level. Other countermeasures such as modified rules, attention to environmental factors, etc. have more general relevance. For this reason, the following description of the range cricket injury countermeasures are grouped into three sections: overuse injuries, collision-type injuries and general injury prevention.

Recommendations for implementation, further research and development are given for each set of countermeasures.

OVERUSE INJURIES

Cricketers, like any athlete today, are expected to train harder, for longer, and to commence at an earlier age, if they are to succeed at the elite level. It is therefore not surprising that physicians are diagnosing an increasing number of overuse injuries, as the hours of repetitious practice produce a gradual deterioration in the functional capacity of the body. Training, technique, footwear, surface, rehabilitation, warm-up and conditioning are all factors which can contribute to overuse injuries.

Cricketers can suffer from a range of overuse injuries associated with all aspects of the game including running, throwing, batting and bowling. The most severe overuse injury particularly to the fast bowler is the development of abnormalities in the lumbar spine.

Bowling involves repetitive twisting, extension and rotation in a short period while body tissues and footwear must absorb large ground reaction forces. However, it is the speed and the force of the action that singles fast bowlers out as being particularly prone to injury.

The fast bowler uses one of two bowling techniques or a combination of these, known as side-on, front-on or mixed bowling. Particular bowling techniques predispose bowlers to injury more than do others. Bowling too many overs in a single spell or bowling for too many spells is another factor which predisposes the fast bowler to injury. High performance young fast bowlers are more likely to bowl excessively throughout the growth period when the spine is immature. As a result they are more vulnerable to injury as the forces associated with fast bowling are unable to be absorbed.

Other common overuse injuries in cricket are related to throwing, catching or running although there is no specific literature focusing on these overuse injuries in association with cricket. Throwing can result in overuse shoulder problems, which are believed to be becoming more prevalent at the elite level. Given that bowlers and batters are expected to run long distances during a game, overuse injuries of the legs are also common. Bowlers, whether fast or slow, may predispose themselves to splitting or wearing away of the skin on the finger, which they drag across the seam of the ball to impart spin as it is released from the hand. A wicket keeper may also suffer knee problems, which may be attributable to the unnatural action of repeated squatting.

Recommendations for further research, development and implementation

- Evidence of an association between abnormal radiological features of the lumbar spine and fast bowling has generally been based on cross-sectional prevalence surveys. Prospective studies need to be undertaken to fully explore this relationship.
- Research is required to determine the maximum desired number of overs to be bowled in a single spell. This should also determine the best measure of this with regard to whether it be the number of overs per day, the number of overs per spell or a combination of these two measures. It should determine whether there is a critical number of overs per season.
- Bowling over restrictions should take into account the fast bowlers physical maturity and not just chronological age.
- Regulations for limiting the number of overs bowled by young cricketers should be developed.
- Further research into the biomechanics of fast bowling is required to determine the clustering of factors that lead to back overuse injury.
- Coaches should undergo regular reaccreditation and education updates so that they are informed of the latest information about bowling techniques, etc.
- Research is needed to determine the role of arm rotation on spine loading.
- Research into the mechanisms of overuse injuries to the shoulder and legs needs to be conducted.
- Developmental research into ways to prevent finger injuries in bowler's should be undertaken.
- Fast bowlers should undergo physical training before each season to prepare them for the rigours of their sport.
- The Australian Cricket Board's SPOT program should be promoted and implemented as widely as possible.
- Formal evaluation of the SPOT program should be undertaken.

- Pre-participation screening of elite fast bowlers should be undertaken and ongoing assessments made.

- The possibility of extending the function of Victorian Cricket Association's Fast Bowling Unit to the wider cricketing community should be explored.

- The role of shoe design in preventing overuse injuries should be further explored.

- Information about the potential for overuse injuries needs to be promoted to the wider cricket community. Resources should be developed to achieve this and be evaluated.

COLLISION TYPE INJURIES

Collision type injuries can occur in a number of ways on the cricket field. They can either be as a result of a direct contact with a ball, another player, the ground or the boundary. Body padding, a generally accepted part of cricketing culture, is worn to prevent these injuries. Protective equipment such as pads, gloves and boxes have all become very much part of the culture of the game and worn at all levels of organised cricket.

Direct injuries to the batter occur from the cricket ball. Wicket keepers can suffer a great deal of trauma, especially when on the receiving end of a fast bowler. Fielders also suffer from direct blows with the ball in much the same way as the batter, particularly those in the in-field. There is a large array of protective equipment available for the batter and wicket keepers to prevent ball collision type injuries. Such equipment includes helmets with visors, chest protectors, forearm guards, batting gloves and genital boxes.

Helmets are a relatively new addition to the protective equipment list for cricketers. The effectiveness of helmets in reducing or preventing head injuries is difficult to assess as no studies have recently been reported in this area, and records of head injuries have not specifically been kept. Cricket helmets have developed from the original head protection-only design to include a combined face and head protection helmet.

Recommendations for further research, development and implementation

- Standards for helmets should be refined and promoted.

- Batters should wear cricket helmets and faceguards that conform to Standards.

- Other cricket players such as fielders should also wear protective headgear.

- Helmets with face shields should be worn by batters, wicket keepers and other in-fielders in order to reduce face injuries.

- Cricketing heroes should be encouraged to wear helmets as an example to younger players.

- Investigations should be made into the advantages and disadvantages of development of a multi purpose helmet. Ideally this would have a removable shield and could be used for cycling, horse riding, roller skating as well as cricket and other sports.

- Epidemiological research into the incidence of eye injuries and associated factors should be undertaken.
- Epidemiological research into the incidence of dental injuries and associated factors should be undertaken.
- Mouthguards should be used by wicketkeepers and batters at all times, to prevent dental injuries.
- Body protection is essential for all batters and should include gloves, leg pads and boxes. Forearm guards may also be worn.
- The protective performance of padding needs to be determined and improved, if found to be lacking.
- Gloves and other protective gear should be worn for informal games as well as for competition.
- The development and careful evaluation of new innovations such as low impact cricket balls should be encouraged.
- Developmental research needs to be conducted into cricket bat handle design that can reduce the impact to upper hand and limit compression of fingers during ball impacts

GENERAL INJURY PREVENTION

WARM-UP/CONDITIONING PROGRAMS

Good stretching programs before and after play, comprehensive conditioning and technique's program before and during the season are very important to condition a player's body to help prevent injury. There have been no specific evaluations of the role of warm-up and conditioning programs for preventing cricket injuries.

Recommendations for further research, development and implementation

- More research into the role of warm-up as an injury prevention measure for cricket is needed.
- Research should be undertaken into the benefits of different types of warming-up, cooling-down and stretching practices.
- Research into the optimal duration and frequency of warm-up should be undertaken.
- Information about warm-up, cool-down and stretching techniques should be developed and widely promoted to improve specific knowledge of techniques.

ENVIRONMENTAL CONDITIONS

Outdoor cricket is played on an oval field of flat grass ranging in size from about 90-150 meters across. In the centre of the field is the pitch, a prepared rectangle of concrete or closely mown and rolled grass on a hard patch of earth. Given this playing environment, it is not surprising that factors such as playing surface and weather can contribute to the risk of injury.

Also important in this playing field is the need to eliminate the possibility of injury occurring due to potholes, sprinkler pop-ups and even the occurrence of rubbish on the field.

Recommendations for further research, development and implementation

- Drinking water should be provided at all cricketing events.
- Cricketers should ensure they drink adequate water.
- Appropriate drink breaks should be developed, which benefit the player rather than the game. This could include the possibility of having a drink person on field.
- Cricketers should always use a broad spectrum sunscreen and wear a hat and/or sunglasses if appropriate.
- Cricket events should not be planned for times when there is a likelihood of hot, humid conditions or much rain. Whenever possible, such events should also be cancelled if such weather conditions eventuate.
- Cricket fields should be regularly checked and maintained to eliminate hazards such as potholes, sprinkler pop-ups, loose debris, rubbish etc.

FOOTWEAR

Appropriate footwear is relevant to all cricketers, especially bowlers. No literature describing the selection and the benefits of well designed cricket footwear was identified.

Recommendations for further research, development and implementation

- Further development of appropriate footwear for cricketers should be undertaken, both for fast bowlers and other players.
- Guidelines on how to select an appropriate cricket shoe need to be prepared.
- Cricketers, particularly fast bowlers, with flat feet or high arches should seek professional advice about shoe design and orthotic use.

MODIFIED RULES AND CHILDREN

Kanga cricket, a modified version of cricket, has been developed for primary aged children, to offer them an introduction to the game and a chance to develop skills and progress to more competitive levels. Kanga cricket is played with a specifically designed soft ball, which is similar to a hard cricket ball, yet eliminates the need for protective equipment and reduces the likelihood of injury. The bats and stumps are of light weight moulded plastic and smaller in size. Kanga cricket also has rules about short pitch deliveries.

Recommendations for further research, development and implementation

- Children should be encouraged to play with softer than standard bats and balls as in kanga cricket.
- Children should be encouraged to play Kanga cricket as a means of developing cricket skills.
- Child and adolescent fast bowlers should be taught correct bowling techniques and procedures, including limiting the number of overs and taking appropriate rest periods.

EDUCATION AND COACHING

Instruction clinics on proper cricketing techniques currently occur in school-related organisations. Guidelines are produced by the Australian Cricket Board to aid in school education programs, particularly on Kanga Cricket and the progression to the VicHit program. The large number of recreational players, however, makes this source of information impractical for community based teams. As a result those in a coaching position, need to be fully educated about the correct techniques.

Recommendations for further research, development and implementation

- Coach should undergo regular re-accreditation.
- Coach education schemes should be updated regularly to ensure they provide the most up to date information.
- Instruction clinics for the wider community should be developed and widely disseminated.
- Education resources for informal cricket need to be developed and disseminated.

FIRST AID AND REHABILITATION

Injuries need to be properly managed to restrict the possibility of further damage. Returning to play too early after injury can make the player susceptible to further injury.

Recommendations for further research, development and implementation

- Cricketers should seek prompt attention for their cricketing injuries from a person with first aid qualifications.
- Organisers of events should ensure that there are qualified first aid personnel at all events.
- Injured cricketers should ensure that they allow enough time for adequate rehabilitation before returning to their pre-injury level of activity.

- Research into the effects of rehabilitation programs for cricketers needs to be undertaken.

INDOOR CRICKET

Indoor cricket is a relatively new game in Australian commencing in about 1970. It has grown quickly in popularity with approximately 8% of the Australian population over the age of 16 participating in the sport. Indoor cricket injuries are generally similar to those of the outdoor game.

Recommendations for further research, development and implementation

- Current regulations indicate that batting gloves must be worn in both hands by each batter, the wicket keeper has the option of wearing none, one or two suitable gloves, while players fielding may wear suitable protective equipment, however gloves may not be worn by the fielder unless special circumstances arise were the player has been injured previously. These regulations should be emplaced and enforced.

- All fielders, batters and wicket keepers should wear a pair of gloves.

- Protective helmets with visors should be worn by both batters and wicket keepers.

- Protective body equipment should be worn by batters.

GENERAL RECOMMENDATIONS

- Improved data collection about the occurrence of cricket injuries and their associated factors needs to be developed and maintained.
- Data about injuries and their associated factors in recreational cricketers needs to be collected.
- Data collections should conform to guidelines for sports injury surveillance being developed and promoted nationally.
- Information about preventing cricket injuries should be disseminated widely through cricketing broadcasts, cricket equipment points of sale, cricketing magazines and more general magazines.
- Guidelines for minimum safety requirements for cricket events (including the need for mobile phones, telephone contacts, first aid kits, etc) should be developed and widely disseminated.

1. INTRODUCTION

Cricket has been a part of Australian history since colonisation, with international games first taking place in 1861 (Mandle, 1973). National heroes have been born through their efforts on the cricket field. Spofforth, Murdoch, Trumper, Bradman, Lille, Chapel and today Warne, have all become household names. There is nothing better known in Australian cricket history than the international battle between Australia and England for 'the Ashes'.

Cricket has had a history of being regarded as a leisurely, gentleman's game (Clark, 1996). Today, with a solid ball weighing approximately 156 grams propelled from a distance of 20m at a speed of about 140 km/h to an awaiting batter, it can hardly be called a gentlemanly game (Stockhill & Bartlett, 1993; Corrigan, 1984). This speed is not an unrealistic estimate, with Australian fast bowler Jeff Thompson being clocked bowling at a record 160.45 km/h in December 1975 (Clark, 1996).

The pace of the game, hazards of the play and expectations of the players have all increased over time. Although strictly a non-contact sport, injuries in cricket can result in a number of ways. A direct blow from a cricket ball during delivery or fielding may result in fractures, bruising, or worse, while a fielder may fall or collide with a boundary fence. Players are now recommended to wear an array of protective gear to guard themselves from injury. Probably the most common of injuries, particularly during formal participation of the elite level, are overuse injuries associated with fast bowler (Hardcastle, 1991).

2. AIMS

The overall aim of this report is to critically review both formal literature and informal sources that describe injury prevention measures, or countermeasures, for cricket. In doing so, it provides an evaluation of the extent to which these countermeasures have been demonstrated to be effective.

As a sport generally played only in British Commonwealth nations, the amount of literature published on the epidemiology, biomechanics and prevention of cricket is limited.

Unlike other literature describing cricket injuries, this report does not specifically focus on the epidemiology of cricket injuries, nor does it provide a detailed description of their aetiology. Instead, this report presents a detailed examination of the range of countermeasures promoted to prevent cricket injuries. A brief overview of the epidemiology of cricket 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 for published medical literature (over the past 10 years)
- Sport discus CD-ROM search for published sports literature (over the past 10 years)
- injury conference proceedings scans
- discussions with key Australian cricket injury researchers
- discussions with relevant state and national cricket organisations
- scanning of Internet and world wide web sites.

The literature gathered for this review was critically assessed to determine the extent to which the various countermeasures had been fully evaluated and demonstrated to be effective in preventing injuries. A gradation scale for the strength of the evidence presented in the identified literature was developed. This is shown in Figure 1.

Figure 1: Grading scale for assessing the extent to which countermeasures have been fully evaluated

STRENGTH OF THE SCIENTIFIC EVIDENCE	TYPE OF SCIENTIFIC EVIDENCE
least ↑	anecdotal or informed/expert opinion
	laboratory-based/equipment testing
	data-based evidence (uncontrolled)
↓ **most**	controlled evaluations

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'. This is particularly important for sports injury countermeasures where any change to the nature of the game is an important factor to be considered. In general, changes to factors such as how the sport is played or undertaken, the behaviour of the participants and the level of enjoyment can only be measured during "in-the-field" evaluations.

At the lowest level of proof (ie the "least" evidence end of the scale) are anecdotal reports of injuries and their prevention and comments based on informed or expert opinion. This category would include, for example, statements like "I treated 5 cases of spondylolysis during last year and all would have been prevented if they had used an adequate bowling technique," or "none of the children with head injuries I treated last year were wearing helmets". Of course, some expert/informed opinion carries more weight than others, particularly when it is based on a critical review of available information.

Laboratory-based evidence is a very important source of information about sports injury countermeasures. This category includes reports that have explored equipment design and testing, development of standard testing procedures and biomechanical research, including that performed on animals, cadavers and simulated body tissue such as crash-test dummies. Such information provides detail about the extent to which countermeasures such as padding perform under certain stress and/or impact conditions. Assessment of cricket bowling techniques and the subsequent biomechanical analysis is another example. This research is generally performed under laboratory conditions which are often controlled. However, such conditions may not be a good representation of actual field or playing conditions.

Data-based evidence can take a number of forms. Case-series studies or routine surveillance systems document the incidence of new injury cases over periods of time. Patterns in data can be examined over time to draw conclusions about the impact that countermeasures may have on injury rates. Cross-sectional epidemiological studies provide some information about injury prevalence at a given point of time but are unable to assess the influence of countermeasures on injury rates. Quasi-experimental studies are not controlled evaluations but do enable a comparison of pre-intervention with post-intervention data to examine the effects of some countermeasures.

Controlled evaluations provide the most definitive evidence for the impact of countermeasures. Case-control studies and longitudinal (cohort) studies are common forms of controlled studies. Neither study type allows random assignment of people (or injuries) to test and control groups, though they are examples of natural experiments. A randomised controlled trial is considered to provide the best evidence. In such studies, the units of interest (ie cricket playing position, helmet wearing, etc) are randomly assigned to test and control groups.

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 and an examination of attitudes, knowledge and behaviours is crucial to this. Studies looking at these factors are generally conducted after implementation of a countermeasure and 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, the literature describing these studies is also included in this review.

Another measure of the success of countermeasures is a demonstration of their cost/benefit ratios. This information is often needed by regulatory bodies and those involved in policy or rule making, to inform of their decisions about countermeasures. To date, there have been no studies of the economic benefits of cricket injury countermeasures.

4. PARTICIPATION IN CRICKET

It has been estimated from surveys that 9-12% of Australians over the age of 16, participated in cricket between 1987 and 1991 (Brian Sweeny and Associates, 1991). These surveys have also concluded that 78% of cricket players were male and 22% were female. Furthermore the majority of participants were aged 16-29 (58%). A limitation of these population estimates is that they were based on small sample sizes.

A larger population household survey conducted by the Australian Bureau of Statistics (ABS) in 1993/1994, indicated that 209,767 Australians over the age of 15 years participated in cricket. This number decreased to 195,000 in 1994/95. This survey also showed that the majority of cricketers were male. Although under 15 year olds are likely to make up a large proportion of all those participating in cricket neither of these data sources collected information about people aged under 15 years.

In a 1995 Australian Bureau of Statistics report by McLennan (1995), cricket rated second only to golf as the most popular sport for males and ninth for females. Again the majority of participants were male.

Knox et al. (1996) conducted a survey of adolescent sports participants and injuries in NSW. They found cricket to be the sixth most popular sporting activity, with 15% of all those surveyed being a participant in the game.

5. AN OVERVIEW OF THE EPIDEMIOLOGY OF CRICKET INJURIES

Cricket injuries can be recalled as far back as 1751 when Frederick, the Prince of Wales, who greatly enjoyed the game of cricket, was killed by a strike with a cricket ball (Brasch, 1971).

Despite the historical recognition of injury and possible death resulting from cricket, few well conducted studies have documented the incidence and nature of cricket injuries during a season. Cricket is essentially a British Commonwealth nation sport and given the limited number of countries involved, little international data exists focusing on the epidemiology of injury. Since cricket is one of Australia's most popular summer activities, this overview will focus predominantly on the limited available Australian epidemiological data. A description of hospital emergency department presentation data for cricket related injuries in Victoria will be presented for the first time in Section 5.1.

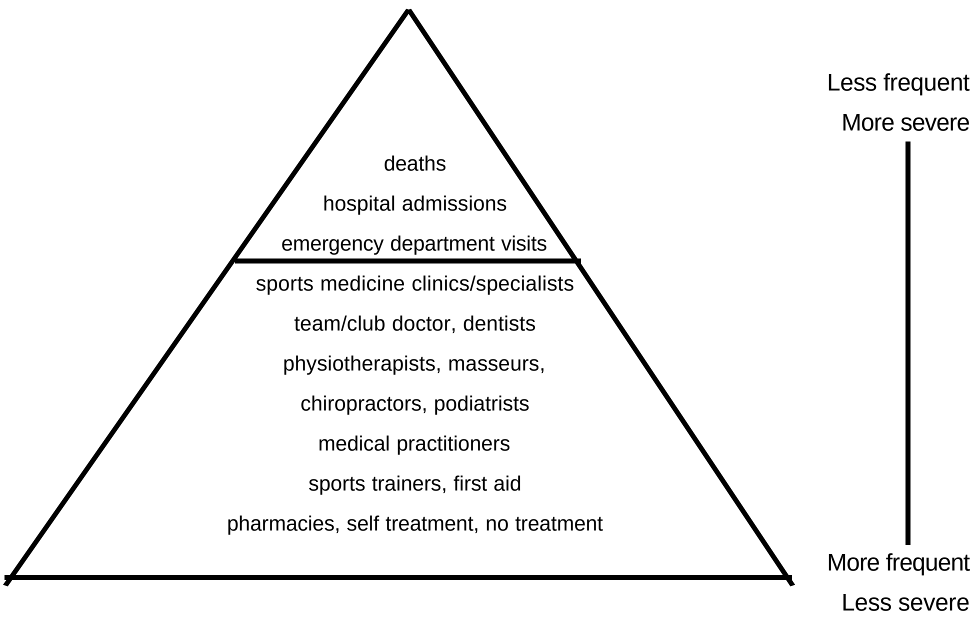
The British Sports Council conducted a survey of injuries amongst 213 teams in eleven sports, including cricket, in North England (Weightman & Browne, 1971). This study reported 251 injuries over a season. In the general British cricket population, the incidence of cricket injuries has been reported to be 2.6 injuries/10,000 hours played (Weightman & Browne, 1971). In first class cricketers in Victoria, the incidence of injury was reported to be approximately 1 injury per 30 man-risk hours (Hoy & Kennedy, 1983). This figure converts to 333 injuries/10,000 hours played.

Finch et al. (1995), reported that cricket injuries amongst adults (>15 years) who presented to emergency departments in Australia accounted for 7.3% of all sporting injury cases. This ranked cricket injuries as the fifth greatest source of sports-related emergency department presentations. At the time of injury, 94.6% of injured cases were involved in cricket as a formal sporting activity (organised competition or practice: 82.8%; informal cricket: 7.1%; unspecified: 4.7%). The remaining 5.4% of cricket injuries presenting to emergency departments occurred during recreational cricket activities. This study also provided information about the body regions injured whilst participating in cricket. The upper extremity was the most commonly injured body region (32.6%), followed closely by lower extremities (22.8%) and head injuries (16.6%). The injuries recorded were predominantly sprains/strains (26%), fractures (20.7%) and bruising (19.6%).

Among children, cricket injuries contributed 3.7% of all sports-related injuries, ranking it the eighth most common cause of sports-related injuries leading to child emergency department presentation (Finch et al., 1995). Amongst this group formal sporting activities contributed 77.1% of all cricketing injuries (organised competition or practice: 40.4%; informal sport: 25.7%; unspecified: 11%). Recreational cricket accounted for 22.9% of all injuries. Head injuries were the most common injury (44.2%), followed by upper extremity injuries (33.9%).

The range of possible modalities and places for sports injury treatment, limits this study’s representativeness of sports injury data collections as it is based on just one source of data from a particular place of treatment (Finch et al., 1995). As is shown in Figure 2, emergency department presentations represent injuries at the less frequent, more severe end of the scale. It is likely that the majority of cricket injuries, particularly overuse ones, would seek treatment from sources towards the “more frequent, less severe” end of the pyramid. Unfortunately, there is less data available for these sources of treatment.

Figure 2: A sports injury pyramid

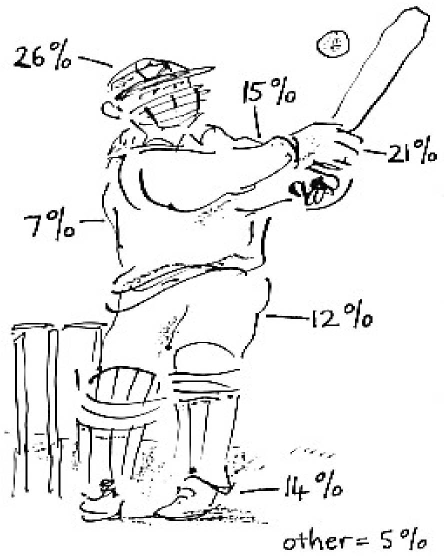


Source: Finch et al., 1995

Similar findings, with the same limitations, were reported by Routley & Valuri (1993). In this report of adult cricket injuries in Victoria, it was found that people injured in cricket contributed to 9% of all sporting injuries presenting to hospital emergency departments and 6% of all sports-related admissions following emergency department presentations. In this Victorian study, males were the predominant group injured representing 91% of cases, as were those aged 20-24 years (33%). Injury resulted from being hit by a moving object in 60% of cases, with the ball being the cause of injury in 85% of these cases. Over-exertion and strain accounted for 21% of cricket related emergency department presentations. The most frequently injured body region was the head/face (26%). This proportion is higher than that for any other sport according to the Victorian Injury Surveillance System (VISS) data (Routley and Valuri, 1993). Injuries to the face, cheek, forehead and scalp accounted for 39% of these head/face injuries. Injuries to the eyes accounted for a further 23%, the nose 12%, mouth 9% and concussion resulted in 7%. The ball caused 87% of the head/face injuries.

Figure 3 shows the most commonly injured body regions amongst adult cricket-related emergency department presentations recorded by VISS. Hand injuries accounted for 21% of all injuries with the majority of these (68%) occurring to the fingers, resulting in fractures (27%), dislocations (13%) and sprains/strains (13%) (Routley & Valuri, 1993).

Figure 3: Adult cricket injuries by body part recorded by the Victorian Injury Surveillance System.



Source: Ann Jones.
Reproduced from Hazard, 15, 1993,

The Victorian Injury Surveillance System (1991) also reported that cricket was responsible for 13% of sporting injuries sustained by children (Routley, 1991). Of these, 86% of cases were male. Seventy percent of cases were aged 10-14. The head and face were the most frequently injured site followed by the fingers and elbow/wrist/forearm. Of those with facial injury, only 6 reported wearing a helmet and none with a face shield. The majority of injuries resulted from being hit with a bat or ball.

A South African study of 308 male cricketers, who played cricket for their province's top team at the National Cricket Club Championships seasons, provided incidence rates for the different positions of play and body sites (Stretch, 1992).

Table 1: Position of play during which injuries occurred (%)

	Bowling	Batting	Fielding	Total
Head, neck, face	-	4.5	4.6	9.1
Upper limbs	3.4	4.6	26.1	34.1
Back and trunk	17.0	2.3	-	19.3
Lower limbs	21.6	5.7	10.2	37.5
Total	42.0	17.1	40.9	100

Source: Stretch (1992).

The principal finding of this study, was that cricket injuries are common in club and provincial players in South Africa, with a 49% seasonal incidence rate of injury being recorded. Younger players sustained more injuries than older players, with the majority of injuries occurring during matches (69%). Furthermore, 24% were re-occurring injuries from previous seasons and 23% of injuries were re-occurring injuries during the current season. Bowlers suffered a greater percentage of lower limb (22%) and back injuries (17%) than other players and this may be attributed to run-up and the bowling action. Upper limb injuries (26%) were most frequent in fielders with a possible explanation being due to excessive throwing over a large distance. A limitation of this study is the 59% response rate. This could account for the high incidence, as injured players may be more likely to respond (Stretch, 1992).

Stretch (1995) examined the seasonal incidence and nature of injuries in schoolboy cricketers. The overall seasonal incidence of injuries in all schoolboy cricketers was 49%, with the back and trunk being the most common site of injury (33%) followed by the upper limbs (30%) and lower limbs (23%). Of those injured, the seasonal incidence rate in bowlers (47%), was greater than that found in batsmen (30%) and fielders (23%).

Sandor and James (1996) conducted a questionnaire assessment of 33 district cricket bowlers. This group is an important one to monitor since they may progress to State Squad or team level. Twenty-five bowlers reported a total of 34 injuries in the 1995/96 season. About one third of these injuries were to the lower back. Injuries appeared to be associated with the number of bowling sessions per week, between matches. All of those that bowled 3 sessions per week were injured during the season, compared with 75% of those who bowled twice and 67% of those who bowled once.

A comparison of the distribution of injuries across body parts in the studies reviewed here may be found in Appendix 1.

There have also been other studies that have looked specifically at back injuries in fast bowlers. These studies are reviewed in Section 7. Similarly, the studies relating to eye and facial injuries are discussed in Sections 8.1.3 and 8.1.4, respectively.

5.1 EMERGENCY DEPARTMENT PRESENTATIONS

This section presents updated and more detailed data about cricket injuries recorded by the Victorian Injury Surveillance System (VISS). VISS collected detailed information from seven campuses of five Victorian public hospitals; 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. Self reported information on almost 170,000 cases was collected.

Of these, VISS has recorded 8053 sports injuries to children, representing 10% of total child injury cases and 7216 sports injuries to adults, representing 11% of all adult injury cases. Due to differing hospitals and periods of collection the children's and adult data are usually considered separately and will be so for the purposes of this report. In this database, children are defined to be people under the age of 15 years.

The findings for children are based upon 5 years of data, 1989 to 1993, at three hospitals: Royal Children's Hospital, Western Hospital and Preston and Northcote Community Hospital and 4 years of data, July 1991 to June 1995, at Latrobe Regional Hospital - Traralgon and Moe campuses.

The VISS adult injury collection is based upon 9 hospital years of data, the collection periods for each participating hospital are as follows: Western Hospital (11.12.90 to 31.12.92 - 2 years), Preston and Northcote Community Hospital (1.3.92 to 28.2.93 - 1 year), Royal Melbourne Hospital (1.3.92 to 28.2.94 - 2 years) and Latrobe Regional Hospital - Traralgon and Moe campuses (1.7.91 to 30.6.95 - 4 years).

Over these data collection periods, VISS recorded a total of 1237 cricket injuries, representing 8% of children's (<15 years) and 9% of adult (>15 years) sporting injuries (Table 2). More than two thirds of children's cricketing injuries occurred during play of an informal or unspecified nature, compared with only 27% of adult cases for cricket of the same nature (Table 2). Almost half of the adult cases occurred during formal outdoor competition. A further 26% of adult and 6% of child cricket injuries occurred while playing indoor cricket. The injuries that occurred during each of these settings will be described separately in Sections 5.1.1 - 5.1.3.

Table 2: Cricket injury emergency department presentations by age and nature of play

Cricket type	Adult		Children		Total	
	n	%	n	%	n	%
Formal outdoor	295	47	168	27	463	37
Informal/not specified outdoor	171	27	407	67	578	47
Indoor	159	26	37	6	196	16
Total	625	100	612	100	1237	100

5.1.1 Formal Cricket (outdoor)

Forty-seven percent of adult and 27% of child cricket injuries occurred during formal outdoor competition (Table 2). The circumstances surrounding these cases will now be considered.

5.1.1.1 Children

Of the 168 cases of children's formal outdoor cricket injuries, most players (82%) were aged 10 to 14 years and 93% were male. Almost 30% of injuries occurred on a Saturday and were most common in the months of November/December (42% of injury cases) and February/March (30%).

Nearly one-third of cases occurred in areas of education, during regular school hours, reflecting the popularity of cricket as a school sport. Most of the remaining cases occurred at cricket ovals and reserves. Two players did not specify the location where the injury occurred.

Nineteen percent of injuries occurred during training or practice. Thirty percent of players specified they were on the fielding side when injured and another 13% were batting. Of the 30% of cases in which the player was on the fielding side, more than half (56%) were attempting to take a catch when the injury occurred, another 10% were bowling and 10% were wicket keeping.

Forty-seven percent of injuries were caused when a player was hit by the ball (Table 3). Of these, 38% were in the head and face region, especially the nose and jaw. Another 18% of these players were hit on the fingers or hand. Almost three quarters of these cases occurred during the normal course of play, with the remaining 27% during training. One quarter of all players hit by the ball were batters, a further 56% did not specify their playing position.

Other common causes of formal cricket injuries to children included being hit by a cricket bat (18% of total cases), 2% of which were intentionally inflicted; 10% falls; 7% finger injuries received whilst catching the ball and 6% collisions with another player. Ninety-three percent of child outdoor formal cricket injuries were collision-type injuries the remainder being overuse or overexertion. Table 3 shows the causes of injury for players in varying play positions in greater detail.

Table 3: Numbers of outdoor formal cricket injuries to children, classified according to cause of injury and playing position at the time of injury

Cause of injury	Batting	Fielding	Catching	Bowling	Wicket keeping	Not Specified	TOTAL
Hit by ball	20	5	4	3	3	44	79
Hit by bat	-	1	5	-	1	23	30
Fall, slip or trip	1	4	3	-	-	8	16
Overexertion or overuse	-	1	1	2	-	8	12
Finger injury while catching	-	-	11	-	-	-	11
Collision with another player	-	2	1	-	1	6	10
Diving for ball	-	1	-	-	-	-	1
Other	-	-	3	-	-	6	9
TOTAL	21	14	28	5	5	95	168

Twelve percent of injured players recorded the use of safety devices, of whom almost half were batters and 15% wicket keepers. The most common items of safety equipment noted were helmets, gloves, pads and boxes.

Eleven percent of the formal children's cricket injuries were so severe that they required hospital admission. A further 45% of players required significant further treatment, ie, review or referral, particularly to an outpatient department (16% of total cases), a review in the emergency department (14%) or referral to a general practitioner (12%). The remaining 44% of players required minor, or no, treatment.

VISS can record up to 3 separate injuries per case. There were a total of 181 separate injuries sustained by the 168 injured players. Forty-four percent of total injuries were to the head and face, particularly nose fractures (7% of total), face and scalp bruising (5%), concussion (5%) and face and scalp lacerations (4%). A further 17% of injuries were to the fingers, particularly fractures and sprain/strains (each 6% of total injuries) and another 2% were dental injuries.

5.1.1.2 Adults

Ninety-four percent of the 295 adult players injured while playing formal outdoor cricket were male. One third of players were aged 20-24 years, a further 21% were aged 25-29 years and 19% were aged 15-19 years of age.

Almost half (47%) of injuries occurred on a Saturday and 72% occurred during the period from the beginning of November until the end of February. Ninety-four percent occurred at areas for organised sport and 4% at school ovals.

Eighteen percent of injuries occurred during training or practice. Twenty-eight percent of the injured cricketers were batters, a further twenty-seven percent of players specified they were on the fielding side, the remainder did not specify their position of play. Of the 27% of cases in which the player was on the fielding side, nearly half (47%) were attempting to take a catch when the injury occurred, another 18% were bowling and 6% wicket keeping.

Sixty-one percent of injuries occurred when a player was hit by the ball (Table 4). Of these, 27% were hit to the head or face, particularly the mouth and jaw. Another 16% of players were hit on the fingers or hand. More than three quarters of these cases occurred during the normal course of play, with the remaining 22% during training. Forty percent of all players hit by the ball were batters.

Other common causes of formal cricket injuries to adults included falls, slips or trips (9%), over-exertion or over-use injuries (7%), finger injuries received whilst catching the ball (6%), diving for the ball (3%), collision with another player (2%) and being hit by the bat (2%). Thus, collision type injuries accounted for 93% of all cases and overuse for 7%. Table 4 shows details of the causes of injury for players in varying positions.

Table 4: Numbers of outdoor formal cricket injuries to adults, classified according to cause of injury and playing position at the time of injury

Cause of injury	Batting	Fielding	Catching	Bowling	Wicket keeping	Not Specified	TOTAL
Hit by ball	73	11	7	2	3	85	181
Hit by bat	2	-	-	-	-	3	5
Fall, slip or trip	2	4	5	4	-	11	26
Overexertion or overuse	5	1	-	7	-	7	20
Finger injury while catching	-	2	1	-	-	4	7
Collision with another player	-	-	17	1	-	1	19
Diving for ball	-	4	3	-	1	-	8
Other	2	1	4	-	1	21	29
TOTAL	84	23	37	14	5	132	295

Sixteen percent of players recorded the use of safety devices, of whom almost half were batters and 11% wicket keepers. The most common items of safety equipment noted were helmets, gloves, pads and boxes.

The admission rate following an emergency department presentation for formal adult cricket injuries was 3%. A further 56% of players required significant treatments. That is, review or referral, particularly to a general practitioner (23% of total cases), a review in the emergency department (17%) or referral to an outpatients department (13%). The remaining 40% of players required minor or no treatment.

VISS recorded a total of 317 separate injuries sustained by the 295 injured players. Injuries were most common to the head/face and the upper limbs (each accounting for 35% of the total injuries sustained), particularly lacerations to the face and scalp (8% of total), fractured fingers (7%), lacerations to the jaw and lip (5%), bruising to the face and scalp (4%) and dislocated fingers (4%). Finger injuries accounted for 16% of total injuries sustained.

5.1.2 Informal cricket (outdoor)

In addition to the formal cricket injuries above, there were a further 407 children's and 171 adult injuries which related to informal cricket activities. These cases represent two thirds of all children's cricket injuries recorded by VISS and 27% of adult cricket injuries.

5.1.2.1 Children

Sixty-three percent of the injured children were aged 10-14 years and 85% of injured participants were male. Like formal cricket injuries, informal injuries most often coincided with the formal cricket season (69% of cases).

The most common location for children's informal cricket injuries was the home, either their own or home or the home of another person. Thirty-eight percent of cases occurred in such locations. Other common locations for these injuries to occur were school (27%), road or footpath (10%), cricket ovals (6%) and parks (5%). Eleven percent of cases did not specify the injury location.

The most common circumstances surrounding these injuries included being hit by the bat (26% of total cases); hit by the ball (23%); falls, slips or trips (22%); collisions with another player (5%); over-exertions (2%); and jumping from a fence or roof after retrieving a ball (2%). Four children were hit by motor vehicles when playing cricket in the driveway or on the roadway. Four percent of cases were intentionally inflicted by another child and 2% related to the child standing on, or falling onto, glass or nails on the ground. Ninety-eight percent of injuries were due to collision-type events, while the remainder were over-exertion. There were fewer overuse injuries in informal cricket than in formal cricket.

In only 7 of the injured cases was it recorded that the child was wearing any protective equipment; 4 children were wearing gloves, 2 a helmet and 2 pads.

Eight percent of these informal cricket injuries to children were severe enough to require hospital admission. More than half of the injured children required significant treatment, including referral to an outpatient department (19% of total), to a general practitioner (16%) and a review in the emergency department (14%). A further quarter of injured players received only minor treatment and 16% no treatment at all.

VISS recorded 435 separate injuries for these 407 cases. The head and face (40% of total) and the upper limbs (34%) were the most common body regions injured. Bruising to the face and scalp (8%), lacerations to the face and scalp (7%), finger fractures (6%), radius/ulna fractures (4%) and concussion were the most common injuries sustained.

5.1.2.2 Adults

More than 90% of the 171 adult informal cricketing injury cases were to males. Half of the adult informal injured players were aged less than 25 years. Again, the majority of injuries coincided with the formal cricketing season (78% occurring during the period from November until the end of February).

Forty-six percent of injured players did not specify the location where the injury occurred. Of the remaining cases, 20% were at residential locations, 12% at cricket ovals, 9% at parks and playgrounds and 5% on the road or footpath.

One third of injuries occurred when the player was hit by the ball, mostly to the face (30% of hits from the ball) and hand/fingers (30%). Another 23% of players sustained overexertion or overuse injuries, 22% fell (11% of which occurred when they were attempting to catch the ball), 2% collided with another person and 2% were injured diving for the ball. Only 2 players recorded the use of safety devices. Both were wearing gloves.

The admission rate for adults sustaining informal cricket injuries was 8%. Most players (68%) required significant treatments, 29% were referred to an outpatient department, 21% to a general practitioner and 16% required a review in the emergency department. Another 22% required only minor treatment.

Of the 188 separate injuries sustained, 40% were to the lower limbs, particularly ankle sprains/strains (9% of total injuries sustained) and knee strains/sprains (5%). Face and scalp lacerations (3%) and metacarpal fractures (3%) were also common.

5.1.3 Indoor cricket

There were 159 adult and 37 children indoor cricket injuries recorded by VISS. Age and sex patterns mirrored those of outdoor cricket injuries recorded by VISS. However, injuries were more evenly spread throughout the year than outdoor injuries. For example, one quarter of adult indoor cricket injuries occurred in May and June.

Twenty-three percent of adult players stated that they were on the fielding side and 6% were batting when the injury occurred, while the remainder did not specify (Table 5). Of those on the fielding side, more than half were attempting to catch the ball when the injury occurred, 27% were bowling and 11% wicket keeping.

Table 5: Numbers of all-age indoor cricket injuries, classified according to cause of injury and playing position at the time of injury

	Batting	Fielding	Catching	Bowling	Wicket keeping	Not Specified	TOTAL
Hit by ball	7	5	3	1	3	43	62
Hit by bat	1	1	-	-	-	1	3
Fall, slip or trip	3	5	8	1	-	25	42
Overexertion or overuse	4	2	4	4	-	28	42
Finger injury while catching	-	-	14	-	-	-	14
Collision with another player	-	2	-	-	-	7	9
Diving for ball	-	4	-	-	-	-	4
Other	-	-	3	1	1	15	20
TOTAL	15	19	32	7	4	119	196

Adult players were most often hit by the ball (38% of total). Other mechanisms of injury included over-exertion (23%), falling (17%), colliding with another player (4%), diving for the ball (3%), and catching the ball (3%).

Thirty-five percent of child players specified their playing position at the time of injury. Of these, 62% were fielding while the remainder were batting. It is worth noting that there were no recorded bowling or wicket keeping injuries. Injuries to child players most often occurred when the children fell (35%), were hit by the ball (19%), over-exerted (8%), collided with another player (8%) or were hit by the bat (5%). Overall, 92% of all injuries were collision-type and 8% were overuse.

Five adult and 3 child players recorded the wearing of safety equipment. Half reported wearing gloves, 3 players reported wearing knee pads and 1 player wore a box.

The admission rate for both adults and children were 11%, but adult injuries were generally more serious than those to children. Fifty-eight percent of injured adults required significant treatments compared to 24% of child cases. Sixty-four percent of child injury cases required only minor or no treatment.

Fingers were the single most common body region injured in both adult and child injury cases, representing 22% of injury cases in each group. Injuries to the head and face accounted for another quarter of each adult and child indoor cricketing injuries. Adult head injuries were mostly nose fractures, bruising to the face and scalp, eye haemorrhages and swelling of the ocular adnexa. Children's head and face injuries were mostly bruising to the eyes and concussion.

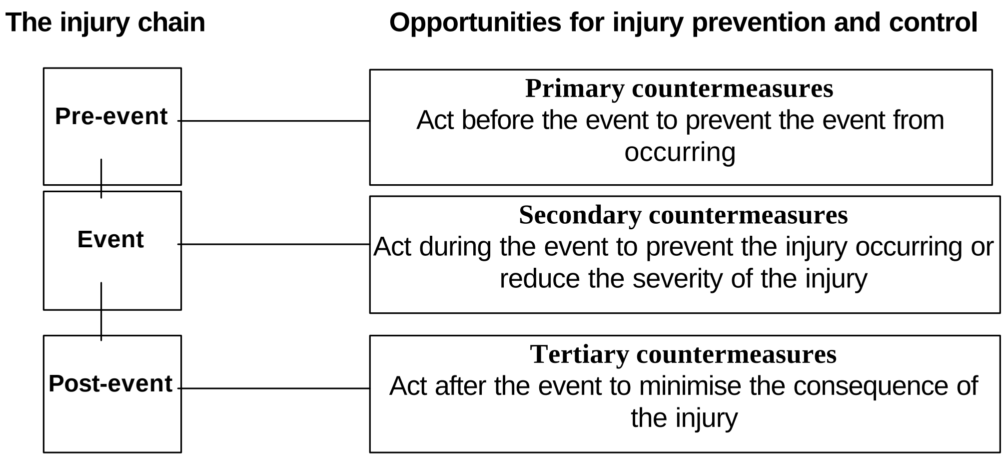
Knee and ankle injuries accounted for a further 12% and 9% respectively of adult injury, particularly strain/sprains and inflammation. Other common injuries to adults included wrist fractures (3% of adult total injuries) and shoulder dislocations (2%).

Bruising accounted for almost a third of child injury, particularly to the eyes and feet (each 5% of total child injury). Other common injuries to children included fractures of the radius/ulna (5%), knee strain or sprain (5%) and concussion (5%).

6. AN OVERVIEW OF INJURY COUNTERMEASURES FOR CRICKET

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). 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 4). 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 4. Countermeasure opportunities in the injury chain



Source: Watt & Finch (1996)

There are a multitude of factors that contribute to the risk of injury in cricketers. Generally, more than one factor is involved in each injury. Consequently there are numerous countermeasures aimed at the primary, secondary or tertiary level which can be considered to prevent these injuries. These are summarised in Table 6.

Table 6: Cricket injury countermeasures

Primary	Secondary	Tertiary
adequate water intake	environment	availability of first aid equipment
attention to biomechanics	footwear	prompt first aid
coach education	protective equipment	rehabilitation
footwear	-helmets	rest, ice, compression, elevation, referral
modified rules	-padding	
nutrition	-gloves	
orthotics	-boxes	
playing environment	-visors	
preparticipation screening	-mouthguards	
pre-season conditioning	surface	
technique		
training		
UV protection		
warm-up		

Sports injury risk factors can also be described as intrinsic or extrinsic factors (Kannus, 1993). Intrinsic, or internal, factors are related to levels of physical and mental health of the athlete. Extrinsic, or external, factors refer to factors are those which impinge externally on the athlete's performance. Different countermeasures are used to address the intrinsic and extrinsic risk factors. Table 7 re-categorises the countermeasures given in Table 6 into intrinsic and extrinsic factors. Typically, the intrinsic factors are addressed by primary prevention activities. Attention to extrinsic factors involves primary, secondary and tertiary levels.

Table 7: Intrinsic and extrinsic factors associated with cricket injury countermeasures

Intrinsic factors	Extrinsic factors
biomechanics correction	adequate water intake
nutrition	coach education
orthotics	distance
preparticipation screening	footwear
pre-season conditioning	first aid
rehabilitation	modified rules
technique	playing environment
	protective equipment
	rehabilitation
	surface
	training
	UV protection
	warm-up

In the next section, the literature assessing the effectiveness of the various countermeasures for the prevention of cricket injuries listed in Table 6 and Table 7 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.

Collision type injuries are probably the most common injuries during informal cricket activities (Ross, 1996b). These include hits by the ball or bats and collisions with the game surrounds (e.g. fence) or other players. Protective equipment and game rules have developed largely to prevent these injuries. At the more formal level, overuse injuries are common and attention to technique is an important countermeasure. Other countermeasures such as modified rules, attention to environmental factors, etc. have more general relevance. For this reason, the following review of the range cricket injury countermeasures is grouped into three sections: overuse injuries, collision-type injuries and general injury prevention.

7. OVERUSE INJURIES

7.1 Rationale and background

Cricketers, like any athletes today, are expected to train harder and longer, and to commence at an earlier age, if they are to succeed at the elite level. It is, therefore, not surprising that physicians are diagnosing an increasing number of overuse injuries, as the hours of repetitious practice produce a gradual deterioration in the functional capacity of the body (Harvey, 1983; Micheli, 1983; Elliott et al., 1993). An overuse injury results from an accumulation of stresses to the involved tissue - bone, ligaments or tendons. The tissue and anatomic sites of an overuse injury may vary but according to Herring and Nilson (1987) the cause is still the same: repetitive episodes of trauma overwhelming the body's ability to repair itself. Once an overuse injury develops, the condition remains until physiological equilibrium is re-established between the stress load and the body's healing ability (Ting, 1991).

Training, technique, footwear, surface, rehabilitation, warm-up and conditioning are all factors contributing to overuse injuries with numerous primary, secondary and tertiary factors playing a role in prevention (refer Table 6).

Payne (1987) outlined the following array of risk factors which contribute to overuse injuries:

- Training errors, including abrupt changes in intensity, duration or frequency of training.
- Musculotendinous imbalance of strength, flexibility, or bulk.
- Anatomic malalignment of the lower extremities, including differences in leg strength, abnormalities of rotation of the hips, position of the kneecap, low legs, knock knees, or flat feet.
- Footwear, improper fit, inadequate impact absorbing material, excessive stiffness of the sole, or insufficient support of hindfoot.
- Playing surface, concrete pavement versus asphalt, running track, dirt or grass
- Associated disease state of the lower extremity, including arthritis, poor circulation, old fracture, or other injury.
- Growth, in particular the growth spurt.

7.2 Overuse injuries of the spine

Cricketers can suffer from a range of overuse injuries associated with all aspects of the game including running, throwing, batting and bowling. The most severe overuse injury, particularly for the fast bowler, is the development of abnormal radiological features in the lumbar spine. This is a current concern, with many young and talented bowlers, suffering from back injuries before they reach an elite level. Indeed, Fitch (1987) describes fast bowling as one of the most injury liable non-contact activities in cricket. Figure 5 summarises the range of factors that may predispose fast bowlers to back injury (Foster et al., 1989). These shall be discussed in future sections

Figure 5: Model of predisposing factors to back injury in fast bowling

Physical characteristics

Posture
flat feet

Strength
reliance on upper body strength to generate ball velocity

Technique faults

Back Foot Impact (BFI)
Excessive shoulder rotation to attain a side-on position between BFI and FFI

Front Foot Impact (FFI)
Higher release position caused by larger knee and hip angles (less dissipation of force)

+

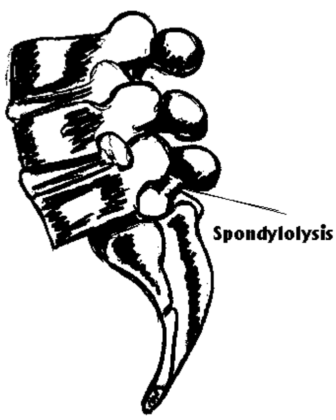
Overuse
Too many overs
Too long a single spell

BACK INJURY

Source: Foster et al., 1989

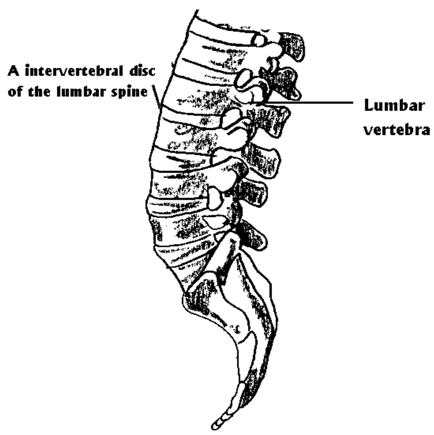
Overuse injuries amongst fast bowlers are generally to the lower spine. The fast bowler can suffer from the development of abnormal radiological features in the lumbar spine. They include a range of debilitating and painful damage to the lumbar spine (Elliott et al., 1992):

Spondylolysis:



A single or double fracture on the pars interarticularis (i.e. the division or part between articulating joints). Spondylolysis is virtually unknown at birth, unusual under 5 years of age and rises thereafter to level out after the age of 20 years (Wiltse et al., 1975; Bell, 1992). The incidence in the general population is about 5% (Bell, 1992).

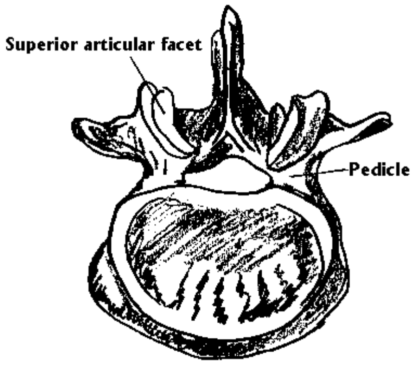
Intervertebral disc degeneration:



The intervertebral disc is a body which is hydrated with fluid. Degeneration occurs when it is progressively converted to a body without fluid.

More extensive disc degeneration can occur when the outward component of the disc extends beyond the margin of the vertebrae. This latter process is also referred to as premature ageing of the disc.

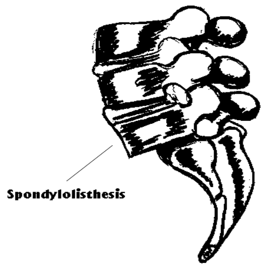
Pedicle sclerosis:



An increase in bone density of the pedicle, pars interarticularis and occasionally, the posterolateral margin of the vertebrae.

This indicates a physiological stress reaction.

Spondylolisthesis:



A vertebral body displaced anteriorly on the vertebral body below it. This is often caused by a bilaterial (i.e. double) spondylolysis, but occasionally it can be due to pars interarticularis elongation.

Abnormal radiological features can result from hereditary factors, incorrect bowling technique, poor preparation or overuse. In the fast bowler, it is believed that these abnormal radiological features result from a combination of repetitive movements such as twisting, bending and rotating (Elliott et al., 1993). Hardcastle et al. (1991) suggested that technique was probably the most important factor in causing back injuries to the fast bowler. The authors noted that, regardless of how physically fit the cricketer may be, if the bowling technique used involves hyperextension and/or excessive twisting of the spine then there is a significant risk of developing a back injury.

The increase in back injuries to fast bowlers in the early 1980s was attributed by the popular press to their inability to achieve a side-on action during the delivery stride (Elliott et al., 1995). This attributing of injury to a faulty action alone was probably over simplistic, as the problem is more multifactorial in nature.

Abnormal radiological findings have also been associated with the impact forces involved in the bowling stride. The bowler experiences a series of impacts with the grass in the run-up followed by two large impacts due to landing on the back, and then the front foot, on very hard turf or concrete. During delivery, these forces are transmitted through the bones, cartilage, tendons, ligaments and muscles of the foot, leg, thigh and pelvis to the discs in the spine and the facet joints of the vertebrae (Elliott et al., 1995). Peak vertical ground reaction forces (GRF) of 4.1 to 9 times the bowlers body weight have been recorded when the front foot is planted on the ground (Elliott et al., 1986; Mason et al., 1989). Given the body movements and bowling technique used, plus the fact that during a day's play the average bowler will run 5 to 6 kilometres, walk a further 10-15 kilometres, and most first class bowlers will deliver 300 to 500 balls a week over a season, as well as the GRF involved in delivering the fast ball it is not surprising that abnormal radiological findings occur (Hardcastle, 1991).

7.3 The bowling technique in regard to the fast bowler

Fast, medium and slow bowling involves repetitive twisting, extension and rotation in a short period while body tissues and footwear must absorb the large ground reaction forces. It is the speed, and thus the force of the action, that makes the fast bowler stand out as having a higher incidence of injury.

The bowling action itself, can be divided into three stages: the run-up to back foot impact (BFI), the delivery stride and the release. The run up to the BFI is the movement of the bowler from stance (i.e. a standing position) to the landing of the back foot. The delivery stride is the period between the back foot impact and ball release. The release phase occurs when the ball actually leaves the hand and has been delivered to the receiving batter. These actions entail a large variety of biomechanical aspects, which shall be described in detail in reference to the fast bowler and the incidence of injury. Detailed biomechanical findings from these studies can be found in Appendix 2.

7.3.1 The run up to back foot impact

The aim of all fast bowlers is to have a well-measured approach, building up to optimum speed about 3 to 4 strides before delivery of the ball (Elliott et al., 1986). The speed at which a fast bowler approaches the wicket influences the velocity of the ball at release (Stockhill & Bartlett, 1993). It also largely determines the alignment of the hips and shoulders at back foot impact and therefore the type of bowling action used (Elliott et al., 1986; Foster et al., 1989; Burnett et al., 1995). It is believed that a too fast run-up makes it difficult for a bowler to convert comfortably to a side-on delivery action.

Conversely a too slow a run-up will reduce the contribution of the linear velocity (i.e. rate at which the body moves in a straight line from one location to another) of the hip relative to the ball (Elliott et al., 1986).

It is for this reason that researchers have looked at these biomechanical aspects of the run-up to the BFI. The approach velocity and the speed of the run-up was however found to not contribute to the incidence of abnormal radiological features (Foster et al., 1989).

The angle of the back foot and shoulder alignment are thought to be significant in the incidence of abnormal radiological features as they determine which bowling action a bowler uses (i.e. side-on, front-on or mixed action) (Elliott et al., 1986). Bradman (1958) summed up this phase of the delivery by stating that the wind-up is the most important phase in attaining a side-on bowling action as errors at this stage cannot be compensated for later in the movement (Elliott et al., 1986).

Back foot alignment indicates the angle at which the foot is placed in reference to the wicket/square leg region. Back foot alignment was not, however, found to be a significant factor relating to the incidence of radiological features in a number of studies (Foster et al., 1989; Elliott et al., 1992; Elliott et al., 1993).

Elliott et al. (1986) indicated that positioning of the back foot may influence the angle of the shoulder as the bowler moves into the delivery stride. However, shoulder alignment was not found to be a factor contributing to the incidence of radiological features in studies by Foster et al. (1989) and Elliott et al. (1993). In contrast, Elliott et al. (1992) found shoulder alignment to be significantly higher (more front-on alignment) in those with radiological features than those without.

The bowler also experiences a series of impacts with the surface during the run-up and delivery phases. These forces are transmitted through the bones, cartilage, tendons, ligaments and muscles of the foot, leg, thigh and pelvis to the intervertebral discs and the facet joints of the vertebrae (Nigg, 1983; Elliott et al., 1995). Mason et al. (1989) stated that these forces could be absorbed by the body, but, when combined with a bowling technique that changes the axis of stress to the pars area, these forces could cause bony abnormalities. Back foot impact ground reaction forces were not found to be significantly related to radiological features in a study of fast bowling technique and the incidence of back injury conducted by Elliott et al. (1992).

Foster et al. (1989) explained the situation as follows: if the spine is erect, which is the case in the side-on bowling position, the intervertebral compressive forces developed through impact is more likely to be resisted by the bowler's intervertebral discs. However, in a lordotic posture (i.e. a forward curvature of the lumbar spine) or when the spine is hyper-extended, as with a mixed bowling technique, the facet joints may bear more of this compression force.

7.3.2 The delivery stride

The delivery stride contains the greatest risk for back injury in fast bowlers because the trunk experiences high degrees of lateral flexion, hyperextension and rotation when ground reaction forces are at their highest levels (Elliott et al., 1986, 1989;1992; Foster et al., 1989; Mason et al., 1989). The delivery stride can be further broken into separate segments: the stride length, stride alignment and shoulder alignment.

The stride length refers to the distance between the back foot impact and front foot impact. It has been suggested that those who approach the bowling crease at too high a velocity have a shorter delivery stride. This may inhibit their ability to master a side-on delivery and thus predispose them to injury. However, a number of studies have found no significant association of those with radiological features and mean stride length at delivery (Elliott et al., 1986,1992, 1993; Elliott & Foster, 1989).

The second important factor in the delivery phase is the stride alignment. It has been recommended that the back foot, the front foot and stumps (wickets) should form a straight line during the delivery stride (Elliott and Foster, 1989; Elliott et al., 1992). Despite this recommendation, Elliott et al. (1992) reported no significant differences among the defined groups of those with no abnormal radiological feature, those with disk degeneration or those with spondylolistic features. The stride alignment reported in this study was thought to indicate an attempt by the bowler to obtain a side-on alignment by positioning the front foot to the side of the wicket. This is fine for side-on bowlers, but will force the spine of front-on bowlers into a rotated and hyperextended position if they adopt such a stride alignment (Elliott et al., 1992). Thus counter-rotation is the key to injury (Elliott, 1996).

Shoulder alignment refers to the movement of the shoulders between the back foot impact (BFI) and front foot impact (FFI). This is a stage in the delivery phase that is believed to be of prime importance in predisposing the lumbar spine to injury (Elliott et al., 1986; Foster et al., 1989; Hardcastle et al., 1991; Elliott et al., 1992). For example, a significant difference was noted between the minimum shoulder alignment of those with abnormal radiological features and those without these fractures in a number of studies (Foster et al., 1989; Elliott et al., 1992).

In contrast to the above studies, Elliott et al. (1992) suggested that mean shoulder alignment may not be the predisposing factor in the appearance of abnormal radiological features in the lumbar spine. These authors argued that in bowlers with appropriate lower body orientation, the shoulder orientation would not cause excessive hyperextension of the spine with this rotation of the trunk.

It has also been suggested that ground reaction forces during the delivery phase can also lead to radiological features. However, this contention was not supported by the studies of Elliott et al. (1992) or Foster et al. (1989).

7.3.3 The release

The final stage of the bowling action is the release phase. The release phase occurs when the arm extends and the ball is delivered. Finally, a follow through action is taken.

When expressed as an absolute value, or a percentage of the standing height, the height of release has been found to be significantly related to the occurrence of stress fractures of the lower lumbar spine. In other words, bowlers who sustained stress fractures tended to deliver the ball from a greater height than bowlers who were not injured (Foster et al., 1989, Elliott et al., 1992).

In another study, however, Elliott et al. (1993) found no relationship between height of ball release to standing height and the incidence of radiological features.

The extension of the front knee joint during the release phase is also an important biomechanical aspect of fast bowling. Bowlers flex the knee joints between front foot impact and release to dissipate ground reaction forces (Elliott et al., 1993). It has been suggested that this reduces the height of release and the incidence of radiological features (Foster et al., 1989). This suggestion, however, was not supported by a study of disk degeneration and the young fast bowler in cricket (Elliott et al., 1993).

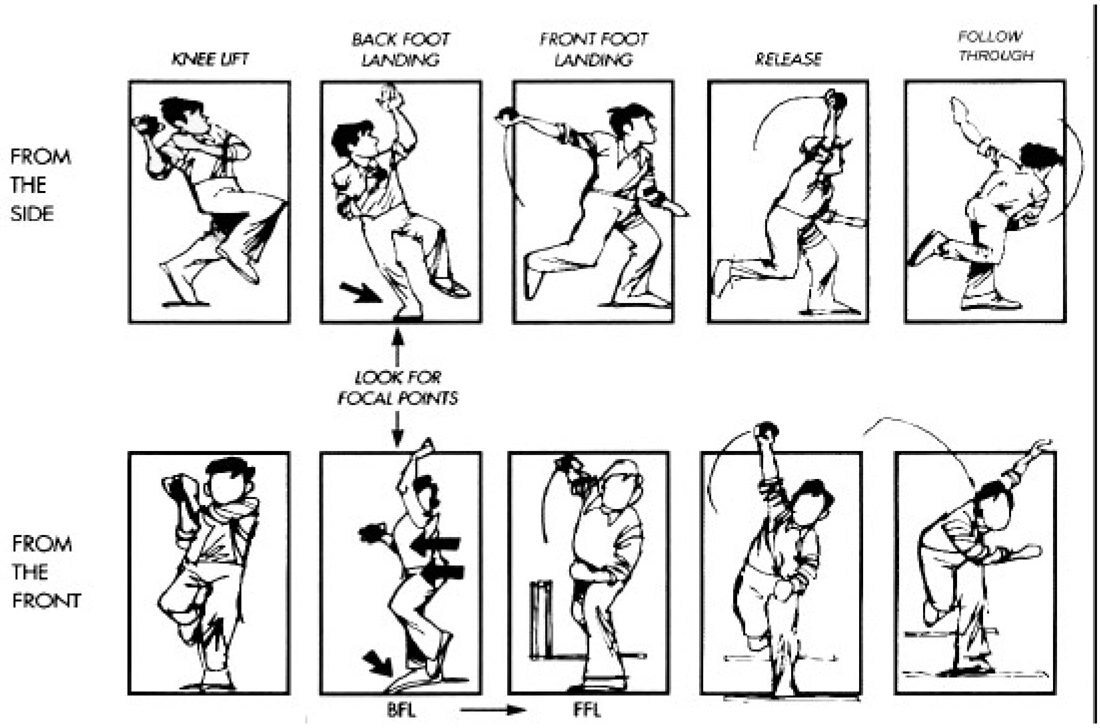
7.3.4 Bowling technique, side-on, front-on or mixed

The bowling action is viewed in terms of the three biomechanical stages as described in Sections 7.3.1 to 7.3.3. These stages determine a bowler's technique. It appears that individually the length of the delivery stride, the mean stride alignment etc. do not significantly influence the rate of abnormal radiological features. When considered together, however, as a united movement, there does appear to be evidence that particular bowling techniques predispose bowlers to injury more so than do others (Annear et al., 1989; Foster et al., 1989; Hardcastle et al., 1991; Elliott et al., 1992; Elliott et al., 1993; Burnett 1996).

The fast bowler uses one of two bowling techniques or a combination of these, known as side-on, front-on or mixed bowling (Elliott et al., 1993):

Side-on action — This action involves a shoulder alignment of 190˚ or less and a back foot angle of 280° or less where the right hand horizontal is a line drawn through the leading shoulder parallel with the pitch (Figure 6).

Figure 6: The side-on bowling action



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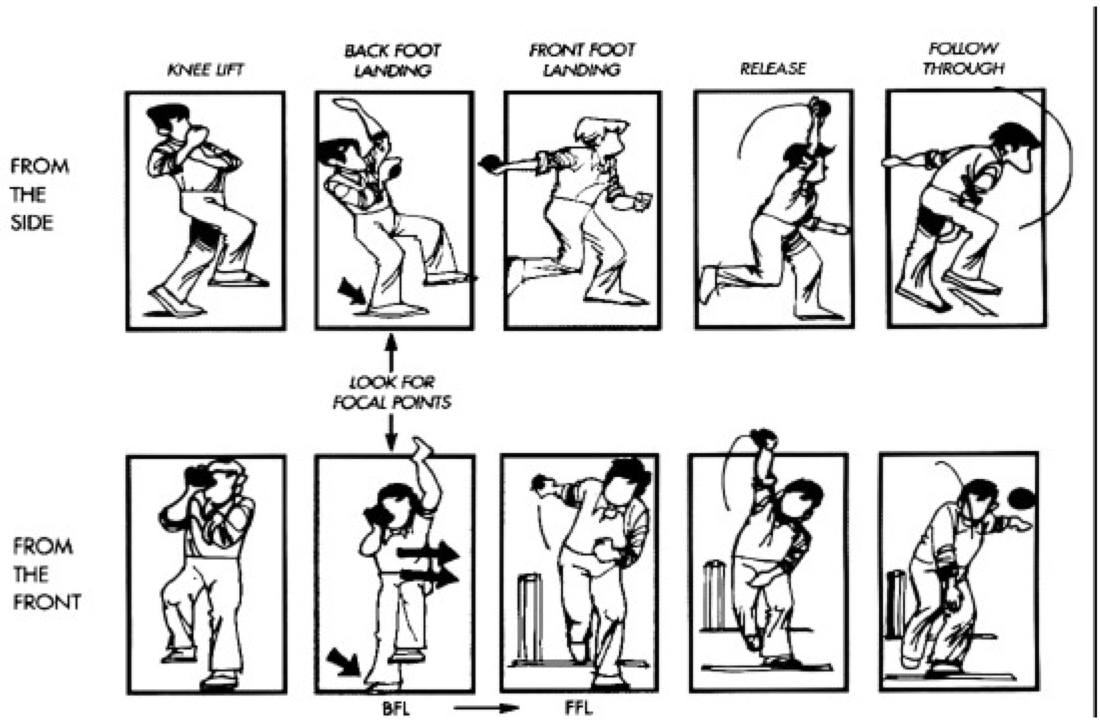
Front-on — The second technique is referred to as the front-on action (Figure 7). The front-on action involves a shoulder alignment greater than 190° and a back foot angle greater than 280° (Elliott et al., 1993).

Figure 7: The front-on bowling action



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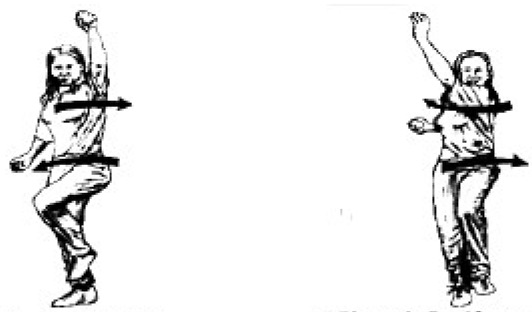
Mixed action — In the mixed or combination action, the bowler is front-on at the back foot impact. In an attempt to obtain a more side-on alignment for delivery of the ball, the bowler counter-rotates the shoulders to decrease his shoulder alignment at the front foot impact (Figure 8). This results in stretching and twisting of the spine as well as excessive shoulder rotation.

Figure 8: The mixed bowling action



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The side-on bowling technique is associated with the lowest incidence of injury as it reduces the degree of extension and lateral flexion of the lower back (Annear et al., 1989; Foster et al., 1989; Hardcastle et al., 1991; Elliott et al., 1992; Elliott et al., 1993; Burnett 1996). The mixed action is believed to result in excessive twisting of the spine which leads to the adoption of a hyperextended and laterally flexed position of the spine at BFI. This places considerable stress on the lumbar spine making it prone to injury (Foster et al., 1989; Elliott et al., 1992).

Elliott et al. (1992) demonstrated that the side-on bowling technique had the lowest incidence of injury in their study of 20 members of the West Australian fast bowling squad. Bowlers who used the mixed technique had the highest rate of radiological abnormalities and no bowler using this particular technique was free of abnormal radiological features.

In another study, Elliott et al. (1993) examined 24 young fast bowlers of whom four used side-on techniques, five used front-on techniques and fifteen use a mixed technique. These authors found that all of the bowlers with identified abnormal discs on the magnetic resonance imaging (MRI) scan used a mixed action bowling technique. No bowlers who used the side-on or front-on technique had abnormal discs in the lumbosacral region.

In a similar population group, Burnett et al. (1996) found that bowlers who used a mixed technique at both the first session and the second session (2.7 years later) had a greater chance of showing progression of disc degeneration when compared to bowlers who used the mixed technique during one season only.

Annear et al. (1989) found that all bowlers who were pain free and had no radiological evidence of spondylolysis or pedicle sclerosis adopted a side-on action for bowling. In comparison, those who used a mixed technique had a 75% prevalence rate of spondylolysis.

Hardcastle et al. (1991), in a study of West Australian under 19 year old fast bowlers reported a significant increase in the prevalence of disc degeneration between fast bowlers with normal action (side-on or front-on) (25%) and those with abnormal or mixed actions (69%).

Foster et al. (1989) found that of the 15 bowlers with a front-on shoulder orientation, eight sustained some form of back injury over one season. In contrast, only one of the nine subjects with a side-on technique sustained a back injury.

7.4 The incidence and type of back injury

Bony abnormalities have been reported to include spondylolysis, spondylolisthesis and pedicle sclerosis (Elliott et al., 1992; Burnett, 1996) (refer Section 7.2). As indicated in the following studies, the prevalence of specifically diagnosed spinal injuries, as well as bony abnormalities have been reported.

An investigation of 24 young male fast bowlers with a mean age of 13.7 years, was conducted by Elliott et al. (1993). The participants who bowled competitively at school and club level were recruited from five Western Australian schools. Bowlers were bowling freely at the time of testing and underwent magnetic resonance imaging (MRI) to detect the incidence of spine disc abnormalities. The bowlers were also filmed side-on and from directly above. The occurrence of abnormal radiological features were used to group the bowlers: group 1, no abnormal features; group 2, disc degeneration and/or bulging on scan. Almost one-quarter (21%) of the fast bowlers in this study showed signs of intervertebral disc degeneration. No cases of spondylolisthesis were found.

The above bowlers were reassessed approximately 2.7 years later by Burnett et al. (1996). This follow-up study investigated 19 of the original 24 young male fast bowlers and the same methodology was used. During the 2.7 year period there was a significant increase in the occurrence of disc degeneration, from 21% to 58%. There was also an increased incidence of back pain from 5% to 53%. The number of bowlers with disc degeneration increased from four to eleven. It must be stated that disc degeneration starts during the second decade of life and is known to increase with age (Miller et al.; Parkkola and Kormano, 1992; Elliott et al., 1995). Thus the results of this study may not be due totally to fast bowling (Burnett et al., 1996).

Elliott et al. (1992) investigated the influence of fast bowling and physical factors on radiological features in high performance young fast bowlers with a mean age of 17.9 years. Twenty members of the Western Australian fast bowling development squad, who had previously undergone routine computed tomography (CT) and MRI scans to detect the presence of bony and intervertebral disk abnormalities, acted as subjects for this study. Bowlers were grouped according to the occurrence of abnormal radiological data. The incidence of bony abnormalities was reported to be 55%. Forty-five percent of bowlers were found to have reported spondylolytic incidences (25% spondylolisthesis, 20% spondylolysis) and 30% had pars interarticular abnormalities. Disc degeneration was also reported in 30% of bowlers. Of the 11 bowlers with abnormal radiological features, 73% had experienced back pain during the season. Sixty five percent of subjects displayed at least one abnormality of an intervertebral lumbar disc and 69% of this sub-group had experienced pain while bowling.

In an earlier study, Payne et al. (1987) found a higher incidence rate of 50% for the occurrence of bony abnormalities of the lumbar vertebrae in A-grade fast bowlers over a 5 year period.

In a similar population, Foster et al. (1989) examined 82 injury free high performance young male fast bowlers with a mean age of 16.8 years. These subjects were nominated by coaches as being the best young bowlers from their club or school. Two weeks prior to the 1986-1987 season, they were tested for selected kinanthropometric and physiological data, and their bowling action was filmed laterally and from above. The bowlers were also required to complete a log book over the season detailing their training and playing programs as well as injuries sustained, along with being assessed by a sports physician using CT. At the completion of the season, the fast bowlers were grouped according to injury status (group 1: bony injury to vertebra; group 2: soft tissue injury to the back that resulted in at least one game being missed; group 3: those with no injury). While Elliott et al. (1992) reported spondylolytic incidents in 45% of bowlers, this study identified an spondylolytic incidence rate of 11%. Twenty seven percent also developed a soft tissue injury to the back region which resulted in at least one missed match.

A prospective study of the West Australian under 19 year old, fast bowling squad was conducted by Hardcastle et al. (1991). This study reported a 58% rate of pars interarticularis defects. Spondylolisthesis was reported in 19% of participants, while 39% of the group had spondylolysis: two had bilateral, and six had unilateral pars interarticular defects. Unilateral defects were present on the side opposite the bowling arm in over 80% of cases. This would suggest that the cause of unilateral defects is not hyperextension but more abnormal twisting of the spine because hypertension is maximal on the same side as the bowling arm (Hardcastle et al., 1991). Hyperextension, however, may be responsible for the bilateral defects and for the presence of spondylolisthesis.

MacKay and Keech (1988) conducted an assessment on all 72 members of the Australian, Victorian and New South Wales under 19 and under 17 fast bowling cricket squads. The assessment consisted of screening procedures, a clinical analysis of the lumbar mechanics, a technical analysis of the lateral and frontal planes using a high speed cinmatography and a work diary recording training and performance. A 20% rate of pars defects was reported.

In contrast to the other studies reviewed above, Annear et al. (1992) looked at 20 of the 23 former fast bowlers with a mean age of 48.3 years who had played state level cricket for Western Australia since its acceptance into the National Sheffield competition in 1948. Each subject was required to complete a questionnaire and undergo a series of radiological tests. It was found that 70% of the subjects had evidence of degenerative changes of the facet joints or disc spaces, 20% showed spondylolysis and 45% had evidence of pars interarticularis abnormalities. As disc degeneration naturally increases with age, and as there was no comparable data collection on a similarly aged group of non bowlers, the results of this study must be taken with caution.

Fifty-six young high performance fast bowlers (U13, U15 and U17) were investigated by Walker et al. (1996). Thirty-four percent suffered at least one degenerative disc, while 14% had bilateral pars defect.

A comparative study of 13 fast bowlers and 10 age, height and weight matched controls who were physically active but non cricketers was conducted by Walker et al. (1995). In the fast bowlers, 21 degenerative discs were identified, compared with 9 degenerative discs amongst the controls .

Appendix 3 summarises the above studies and enables comparisons to be made. In making comparisons between these studies, the following factors need to be taken into consideration: age range, standard of play, hours of play and repetitions of bowling technique occurred. It is also important to note that the studies by Foster et al. (1989)

and Elliott et al. (1992) are the only ones which use a CT scan for detecting abnormalities. CT scanning is superior to standard x-ray methods for detecting abnormal radiological features (Fitch, 1987; Elliott, 1992).

The studies by Elliott et al. (1992) and Annear (1992) also considered pedicle sclerosis, which may be a sign of a developing or healing fracture (Shermann et al., 1977; Annear et al., 1989; Elliott et al., 1995). This has not been examined in previous studies.

7.5 Physical capacities data

Physical capacities data is relevant to all bowlers and refers to general aspects of bowling and bowlers that may be associated with injuries. It is simply the force and speed with which the bowling occurs that defines the physical characteristics as more important for the fast bowler.

7.5.1 Amount of bowling in a season/overuse

Bowling too many overs in a single spell, or bowling for too many spells, is another factor which predisposes the fast bowler to injury. Even with perfect techniques, once fatigue sets in the action starts to fall away. As a result, the body actions change to accommodate the fatigue and thus puts these bowlers into a high risk category (Ross, 1996a).

The repetitive nature of fast bowling itself has been shown to lead to injury. An investigation of 82 young fast bowlers who kept log books of the amount and type of bowling they preformed, found that of the 32 subjects who bowled more than the mean number of matches for the group, 58% sustained a stress fracture or disabling back injury (Foster et al., 1989). This compared with a 38% injury rate for the entire group.

The biomechanics of the bowling technique throughout the duration of a 12-over spell did not vary in a study of 9 members of the Western Australian Cricket Association fast bowling development squad (Burnett et al., 1995). This suggests that in general the fast bowling technique does not change over this length of spell. These conclusions were based on a very small sample and hence must be viewed with caution. Nevertheless, there was some evidence of a change in technique for the fast bowlers who used a front-on action. The change involved counter-rotation of the shoulders. This finding needs to be confirmed by a more comprehensive study (Burnett et al., 1995).

7.5.2 Age

The young cricketer's discs are relatively elastic and forces are more readily transmitted to the facet joints, placing undue stress on the pars interarticularis (Hardcastle, 1991). High performance young fast bowlers are more likely to bowl excessively throughout the growth period when the spine is immature. As a result they are more vulnerable to injury as the forces associated with fast bowling are unable to be absorbed.

Elliott et al. (1992) found that fast bowlers with no abnormal radiological features were significantly younger than those with spondylolysis, spondylolisthesis or pedicle sclerosis (median age, 16.4 years versus 18.4 years, respectively). This result may be interpreted as an increased incidence of abnormal radiological features with more years spent bowling.

In contrast, however, Elliott et al. (1993) investigated 24 young fast bowlers and found no significant differences between those with abnormal radiological features (mean age 14) and those without (mean age 13.5) in terms of any physical capacity measures.

Consideration must also be given to increased incidences with increased age as disc degeneration starts during the second decade of life and is known to increase with age (Miller et al.; Parkkola and Kormano, 1992; Elliott et al., 1995).

7.5.3 Muscle strength and flexibility

When comparing physical tests at the end of a season with those at the beginning of a season, Mackay and Keech (1988) found that the lower lumbar vertebrae became stiff over the off season. They also found that in an activity like fast bowling, a full range of lumbar joint movement in flexion, extension, lateral flexion and rotation is required. Stiff joints at particular interval levels of the lumbar spine may place extra forces on existing hypermobile joints at other levels and cause injury. Tightness in the muscle groups surrounding the pelvis, could result in forward rotation and may increase forward curvature of the lumbar spine.

Foster et al., (1989) found that decreased flexibility in the low back region could increase the possibility of back injuries. Moreover, too much reliance on upper body strength could predispose a bowler to bowl too fast, resulting in back injury. High muscle endurance was also reported as being an important factor, given the repetitious nature of bowling over a long period.

Elliott et al. (1992) reported that bowlers who had poor hamstring or lower back flexibility predisposed themselves to an intervertebral disk abnormality. However, decreased flexibility in this area may be due to the abnormality itself and not necessarily a predictor of subsequent abnormalities.

Further investigations by Elliott et al. (1992) used the sit and reach test to produce functional lower back-hamstring flexibility results. Fast bowlers with disc degeneration or bulging produced a significantly lower sit and reach score (median, 4.5cm) compared to those with no abnormal radiological features (median, 8.0cm). No significant differences existed between groups on measures of strength or endurance for the abdominal or back extensor muscles believed to support and absorb forces during bowling. While participants recorded a mean of 39.4 sit-ups per minute, individually there was no significant difference between the two sets of bowlers for this measure.

It is logical to assume that a body which is physically prepared for the rigours of fast bowling will decrease its likelihood of injury. It is worth noting that the Australian Cricket Board recommends 50 sit-ups per minute, as a base level of achievement.

7.5.4 Fat levels

Excessive body fat may be detrimental to cricketing performance as it does not contribute to energy production and the body must consume energy to support the excess weight (Foster et al., 1989; Elliott et al., 1992). The Australian Cricket Board recommends a mean skinfold level of 35mm (Elliott et al., 1992).

Elliott et al. (1992) found no significant differences for fat levels between groups with a mean fat level of 42.7mm being recorded. This level was produced by summing the skinfolds at four selected sites and dividing by four. An earlier study produced virtually the same results with a reported mean fat level of 43mm (Elliott et al., 1986). Another study by Elliott et al. (1993) produced a different result with the mean sum of skinfolds for the four sites being 32.9mm for the normal radiological group (group 1) and 36.1mm for the group with abnormal radiological features (group 2)

7.5.5 Posture data

Posture involves the anatomic relationship between the skeletal and muscular systems (Elliott et al., 1992). Cricketers with adverse postures, or predisposing genetic problems, may increase their risk of serious injury when bowling a fast ball.

Aspiring fast bowlers with abnormal curvatures of the spine (sideways or front-to-back) must pay particular attention to the physical preparation aspect of their programme, as it can cause a typical curvature of the spine called scoliosis. If already present, repetitious fast bowling may aggravate the condition (Burnett, 1995).

In a study of 82 high performance young male fast bowlers with a mean age of 16.8 years, the height of the longitudinal arch of the foot was significantly related to back injury. Bowlers with a low arch were more likely to develop a stress fracture in the lumbar vertebrae. It may be possible that a foot with a low arch may not be capable of absorbing the high forces at front foot impact as effectively as a foot with a medium or high arch (Foster et al., 1989). This suggests a role for improved footwear design or the use of orthotics (see Section 9.3).

7.6 Preventative fast bowling

The Commonwealth Bank Cricket Academy (a program of the Australian Institute of Sport (AIS)) regards injury prevention as one of its key roles in the implementation of a program aimed at the development of elite cricketers. This applies to all players who attend the Academy, although special attention is given to the fast bowlers due to the stressful nature of that particular part of the game (Done, 1996).

The Australian Cricket Board (ACB), through its National Coaching Committee, promotes an education program to reduce fast bowling injuries entitled “SPOT” (Australian Cricket Board, undated):

- S - screen bowlers at a early age for all risk factors including postural stature.
- P - good physical preparation is essential.
- O - overbowling and overuse should be avoided.
- T - correct technique is also important.

The Australian Cricket Board’s booklet, ‘Prevention of Lower Back Injuries in Fast Bowlers’, states that bowlers concentrating on bowling too fast, for extended periods during practice and match play predispose themselves to lower back injury (Mason et al., 1989). As a result, the Australian Cricket Board has placed the following restrictions on bowlers of medium pace and above: (defined as bowlers from whom the wicketkeeper would normally stand back) (Victorian Cricket Association, 1995):

- bowlers are limited to a maximum of eight consecutive overs in one spell
- bowlers are limited to a maximum of twenty overs in any one day.

The break between spells is to be the equivalent number of overs bowled from the same end of the field as the last over of the bowler’s immediately concluded spell

(Victorian Cricket Association, 1995). A spell is defined as two or more consecutive overs. This regulation also applies to under 19 fast bowlers. Under 17 fast bowlers are restricted to a maximum spell of six consecutive overs, and a maximum daily allocation of 16 overs (Australian Cricket Board, 1995a). These recommended numbers of limited overs are, however, not based on any firm evidence, but represent the "gut feeling" of what may be appropriate (Ross, 1996b).

The Australian Cricket Board has also produced a strategy paper for bowling injury prevention (Australian Cricket Board, 1995a). This paper recognises that the fundamental approach to injury prevention must be through education of coaches, participants and parents, along with appropriate legislation. This includes early screening programs for those at highest risk of injury, by sports professionals as well as limiting the number of bowling overs. These regulations need to be further developed for younger players (Australian Cricket Board, 1995a).

A problem with these regulations, is that talented fast bowlers may be exposed to a higher level of competition, or may play both junior and senior levels on one day (Ross, 1996b). Thus, it is often the star player who breaks down first because they are the ones who are overbowling the most (Ross, 1996b). Ross (1996a) also indicated that one of the things that the VCA is currently researching is at what critical point the fast bowler should stop and have a break from bowling. The VCA is sure this will vary for each individual athlete, particularly for athletes who are at different stages of maturation, despite their chronological age (Ross, 1996a).

The Australian Sports Medicine Federation has prepared "Guidelines for safety in children's sport: cricket". Recommendations include that fast bowlers aged 11 to 13 should undergo a minimum physical preparation which consists of upper body strength (30 push-ups in 1 minute), aerobic fitness (3000m in a 15 minute run), sit and reach flexibility (+5cm) and abdominal strength (30 sit-ups in 1 minute). Physical demand recommendations are also made. These include the fast bowler practicing 2x30 minute bowling sessions per week (under 13 year olds) and 2 spells of 4 overs each (under 13 year olds). Limiting matches to once a week and limiting practice time for those playing with more than one team were also recommended (Australian Sports Medicine Federation, undated).

Kennedy and Fitzgerald (undated) recommended that, younger bowlers be restricted to no more than 6 to 10 overs and in young adolescents 10 to 14 overs.

The Victorian Cricket Association has developed a back injury screening programme aimed at high performance U17 and U19 year old fast bowlers. With sponsorship from Sport and Recreation, Victoria, this has developed into the Fast Bowling Unit for all state-level cricketers. The Fast Bowling Unit, provides expert medical, physiotherapist, biomechanical and fitness training consultations. This will create Australia's leading athlete management program for players in its highest injury risk category (Australian Cricket Board, 1995a). Specifically, the program looks at screening for postural factors, radiological evaluations (if required), fitness testing, biomechanical assessment, technique training and practice organisation (Australian Cricket Board, 1995a). These screenings are conducted three times a year: pre season, mid season, and post season. It is the aim that the information developed through the program will enable the Fast Bowling Unit to become available to the wider cricket community. The present limitations of the activities of the Unit are simply a problem of resources (Ross, 1996b).

During the period 1986-1989, 47% of the Victorian under age state squad fast bowlers had their careers dampened by injury and in some cases they were forced to retire (Ross, 1996a). As a result, the Victorian Cricket Association developed a screening programme for U17 fast bowlers and U19 levels, which was further implemented with the inclusion of cricket as a Victorian Institute of Sport (VIS) program. This injury rate for fast bowlers has since decreased to 36% in the state squad, 11% in the U19 level and is non existent in the VIS cricketers and U17 level (Ross, 1996a).

The ACB has also updated an appropriate abdominal strengthening program for cricket, particularly fast bowlers. This includes a video resource currently being developed by the ACB (Done, 1996).

7.7 Other overuse injuries

Other overuse injuries in cricket can be related to throwing, catching or running, although there is no specific literature focusing on these overuse injuries in association with cricket (Ross, 1996b).

Throwing can result in overuse shoulder problems, which are believed to be becoming more prevalent at the elite level (Ross, 1996b). The cricket player may complain of 'throwing his shoulder out' or when returning the ball from the boundary that 'the ball only went half way' (Crisp, 1989). Repetitious throwing movements may lead to degenerative changes in the rotator cuff, tendinitis in the biceps or a tear of the supraspinatus tendon (Corrigan, 1984).

Given that bowlers and batters are expected to run long distances during a game overuse injuries of the legs are also common. Again, however, specific literature on how to prevent this sort of injury in cricket is limited. Common overuse running injuries relevant to cricketers include stress fractures, shin pain, patellar tendonitis and muscle tears (Corrigan, 1984).

Bowlers, whether fast or slow, may predispose themselves to splitting or wearing away of the skin on the finger, which they drag across the seam of the ball to impart spin as it is released from the hand (Corrigan, 1984). Protective strapping cannot be used and the skin may only heal partially between matches. Corrigan (1984) also indicated that the end or middle finger joints are traumatised repeatedly by the bowling action and sometimes the consequent osteoarthritic changes are severe enough to prevent participation in the sport.

A wicket keeper may also suffer osteoarthritic changes in the knees (Corrigan, 1984). These can be attributable to the unnatural action of repeated squatting.

The injury prevention measures adopted by the Commonwealth Bank Cricket Academy as part of their ongoing program for elite cricketers are (Done, 1996):

- At the start of each year, players are given a thorough medical, physiotherapy, biomechanical (fast bowlers) and podiatry assessment with recommendations to be followed up. Fast bowlers who have any previous record of back injury are also screened using other appropriate methods to assess the current status of the problem.

- Each player follows an appropriate (for training age, age and player type) strength training program including special shoulder and abdominal programs. Special strength assessments are also made at the AIS in Canberra early in the program to enable more specific strength training programs to be set.

- Each player follows a stretching routine aimed at addressing personal weakness (as recommended from the above assessment).

- All physical training sessions and matches include appropriate warm-up and warm-down. A number of recovery methods are also made use of on a regular basis including massage, swimming, stretching and spa pools.
- AIS medical and physiotherapy staff review weekly ongoing problems to ensure any rehabilitation or set programs are progressing according to plan.

7.8 Recommendations for further research, development and implementation

In summary, when comparing fast bowlers to the general population it would appear that particular techniques used in the bowling action and/or overuse lead to a significant increase in the incidence of abnormal radiological features in the spine. Overuse injuries are also common in other cricketers.

Based on this review of the literature and discussions with experts, the following recommendations for further research, development and implementation can be made:

- Evidence of an association between abnormal radiological features of the lumbar spine and fast bowling has largely been based on cross-sectional prevalence surveys. Prospective studies need to be undertaken to fully explore this relationship.
- Research is required to determine the maximum desired number of overs to be bowled in a single spell. This should also determine the best measure of this with regard to whether it be the number of overs per day, the number of overs per spell or a combination of these two measures. It should determine whether there is a critical number of overs per season.
- Bowling over restrictions should take into account the fast bowler's physical maturity and not just chronological age.
- Regulations for limiting the number of overs bowled by young cricketers should be developed.
- Further research into the biomechanics of fast bowling is required to determine the clustering of factors that lead to back overuse injury.
- Coaches should undergo regular reaccreditation and education updates so that they are informed of the latest information about bowling techniques, etc.
- Research is needed to determine the role of arm rotation on spine loading.
- Research into the mechanisms of overuse injuries to the shoulder and legs needs to be conducted.
- Developmental research into ways to prevent finger injuries in bowlers should be undertaken.
- Fast bowlers should undergo physical training before each season to prepare them for the rigours of their sport.
- The Australian Cricket Board's SPOT program should be promoted and implemented as widely as possible.
- Formal evaluation of the SPOT program should be undertaken
- Pre-participation screening of elite fast bowlers should be undertaken and ongoing assessments made.
- The possibility of extending the function of Victorian Cricket Association's Fast Bowling Unit to the wider cricketing community should be explored.

- The role of shoe design in preventing overuse injuries should be further explored
- Information about the potential for overuse injuries needs to be promoted to the wider cricket community. Resources should be developed to achieve this and be evaluated.

8 COLLISION TYPE INJURIES

Collision type injuries can occur in a number of ways on the cricket field. They can be the result of a direct contact with a ball, another player, the ground or the boundary. Body padding, a generally accepted part of cricketing culture, is worn to prevent these injuries.

8.1 Protective Equipment

8.1.1 Rationale and background

In cricket, a solid ball is propelled from a distance of about 20m at speeds around 140 km/h towards the batsperson (Stockhill and Bartlett, 1993; Corrigan, 1984). Within the very short period of time of the delivery a number of decisions have to be made by the batsperson. These include deciding on the line and length of the ball, deciding whether to move forward or back, deciding whether or not to play a stroke and deciding on the stroke to play (Barnes, 1990). These decisions rely predominantly on the reaction time of the batter. If the bowler bowls a predictable ball, then reaction time and play will flow easily. However, laboratory measures of visual reaction time suggest that some aspects of high speed ball games such as cricket are impossible to monitor because there is insufficient time for the player to respond to unpredictable movements of the ball (McLeod, 1987). It is therefore easy to imagine how a fast bowler can deliver a ball to a batter and a collision injury result, when protective equipment is not in use. Similarly, an infield fielder can be exposed to balls of very high speed. Misjudgment of the ball or an unanticipated bounce may result in injury, if appropriate protective equipment is not used.

Protective equipment such as pads, gloves and boxes have become very much part of the culture of the game. They are worn to varying degrees, at all levels of organised cricket.

In a report on the safe practices of sporting clubs in an Australian shire there were 15 cricket clubs. Of these, 10 (66%) indicated that helmets should be worn by batters and close fielders (particularly at junior level), and 8 (53%) indicated that pads, gloves or boxes should be worn by their participants. Despite these figures, some clubs noted that helmets were only worn sometimes (if they were available) (Finch et al., 1995).

Helmets are believed to protect against concussion and other serious, preventable injuries and also help to minimise facial and scalp lacerations (Cross, 1993). However, concussion can still result from sudden acceleration or deceleration of the brain within the skull, especially if the impact has the effect of a sudden jolt. Mouthguards used in sport help prevent injuries to the teeth, lips and jaw, as well as concussive episodes occurring from a blow to the jaw (Morrow & Bonic, 1989; Cross, 1993). Eye visors aim to protect the eyes from serious damage. Boxes are used to protect the genitals. Padding of certain areas of the body such as the hands, thighs and shins also provides some protection against injury.

Today, protective equipment is adopted in the hope of reducing the injury rate and severity. However pre and post intervention injury data are not available to assess the effectiveness of protective equipment (Hrysomallis, 1996a).

Injury data gathered before and after the introduction of cricket helmets and the associated standards is non existent. However the use of helmets as a preventive measure has been well documented in other sports (Bishop, 1993). Likewise, the use of eye and facial visors attached to helmets has not been evaluated, although the benefits of eye or facial protectors in other sports has been documented (Bishop, 1993). Hrysomallis (1996a) conducted a review of the literature and concluded that head and face injuries to batters wearing helmets with facial shields and ear pieces had been rare.

8.1.2 Helmets to protect against head injuries

Helmets are a relatively new addition to the protective equipment list for cricketers. The effectiveness of helmets in reducing or preventing head injuries is difficult to assess as no studies have recently been reported in this area. Furthermore, detailed injury records have not been kept. However, most authors and authorities appear to agree that sport helmets serve the function for which they are designed and do reduce the risk of serious injury to the head and brain (Longhurst, 1991).

The prime purpose of helmets is to prevent head injuries. It is crucial that they are therefore fitted correctly. It has been suggested that helmets reduce anxiety when facing a fast bowler (David & Morgan, 1988). Conversely, there have been some suggestions that they may increase risk due to visual impairment, increase bulk mass, disruption to balance and heat dissipation (Hrysomallis, 1996a). The introduction of helmets to the sport, has probably resulted from the high incidence of head injuries occurring, as indicated by Routley and Valuri (1993).

Standards Australia is currently developing standards for helmets for ball games and cricket in particular, based on a discussion paper by McColough (1993). According to McColough (1993) a request for a standard helmet arose in the early 1980's when a variety of head protection ranging from motor cycle helmets to purpose built helmets were being worn by cricketers. As a result, draft documents have been prepared on protective headgear for cricket: helmets, temple protectors and faceguards along with methods for testing protective helmets. The draft standard on helmets specifies the requirements for helmet use in cricket to mitigate the effects of a blow to the head by a cricket ball. The standard includes construction, strength of the retention system and its attachment points, impact energy attenuation, and labelling requirements.

It is noted, however, that severe direct blows from a cricket ball can still result in injury, even when a helmet is worn. "In such instances, a ball strikes a helmeted head, the ball deforms, the ball decelerates, the helmet deforms, the helmet accelerates and the skull accelerates and slams into the brain (not necessarily in that order)" (McColough, 1993).

In 1995, the Victorian Institute of Sport made it compulsory for all their batters to wear helmets (Ross, 1996a). The Victorian Cricket Association (VCA) follows this recommendation, along with recommending that at junior levels the wicket keeper and close in-fielders also wear helmets (Ross, 1996a). For very young players the VCA recommends that even with helmets, in-fielders should not be within a certain area around the batsperson (Ross, 1996a).

8.1.3 Helmets with visors to protect against eye injuries

Cricket helmets have developed from the original head protection-only design to include combined face and head protection. The first form of face protection was a perspex screen which became hazardous on hot or moist days. Today, the cricket helmet is designed with a grill (Ross, 1996a).

Cricket, as a cause of eye injury, has received very little investigation, with the majority of the limited studies available focusing on all sports related eye injuries.

A prospective cross-sectional survey of all eye injuries treated at the Royal Victorian Eye and Ear Hospital sustained during sporting activities in a two year period (Nov 1989 - Oct 1991) was conducted by Fong (1994). A total of 700 patients with 709 eye injuries, caused by sporting activities, were identified, representing 5% of all eye injuries. Of those injured through sporting activity, 7% were engaged in cricket, and this peaked as expected during the summer months. In the reported cases, there was no mention of protective eyewear being worn by any of the injured cricketers.

In a similar study, Jones (1988) conducted a one year prospective study of all sports injuries requiring inpatient treatment at Manchester Royal Eye Hospital. In this study population, sports accounted for 25% of all severe eye injuries. Of these, 4% resulted from cricket. No patient in this study reported using protective eyewear, nor had any previous experience wearing or obtaining protective eyewear.

MacEwen (1987), surveyed all patients attending two eye infirmaries in England. A total of 246 cases of sport-associated eye injury was identified of which only six related to cricket. In a similar English study, the prevalence of sports eye injuries were registered over 18 months. Of all sports-related eye injuries cricket contributed to 5% (Gregory, 1986).

From the point of view of preventing cricket injuries, these studies are limited because they considered all sports and not specifically cricket. To progress cricket injury prevention, discussions of injury incidence and recommendations for prevention need to be limited to the cricket context. It is difficult to group all sports together and make judgements about the risk of injury as the time of play, nature of the game and energy expenditure can directly reflect the incidence. Jones and Tullo (1986) reported five cases of serve eye injury sustained during cricket, how they were sustained and the nature of injury sustained. All resulted from a strike by a cricket ball.

It is clear that the incidence and prevention of eye injuries within cricket has been given inadequate attention. The studies presented do not focus primarily on the incidence of cricket injuries, nor do they evaluate the benefits of protective eyewear.

8.1.4 Helmets with visors to protect against facial injuries

Facial fractures although not usually catastrophic, can result in long term morbidity and deformity and may require hospitalisation and surgery (Lim et al., 1993). Despite the obvious risks associated with cricket, little data exists on the extent and prevention of facial injuries in this sport.

One hundred and thirty seven patients with sports-related facial fractures were reviewed by Lim et al. (1993). These patients made up 16.3% of all facial fractures seen at the Department of Plastic and Reconstructive Surgery, Royal Adelaide Hospital, between June 1989 and June 1992. Cricket contributed to 14.6% of sporting facial fractures, with the fast flying or bouncing ball being the cause of the injury in all but one case. This was second only to Australian Rules Football which accounted for 52.6% of cases.

An earlier study examining dental and facial injuries over a five year period was conducted by Hill et al. (1985). Based on the data collected the risk of facial injury was highest in rugby (27%), followed by cricket (20%) and soccer (20%). Cricket injuries resulted from being struck by the ball in 70% of cases, while only 15% resulted from bat trauma. The cause of the remaining 15% of injuries were obscure, but included head clashes, falls etc. A particularly interesting result of this study was that the incidence of injury was highest in 40-49 year olds, followed by 0-9 year olds. It was suggested that these results may reflect the reduced speed of reaction and hence movement time, in both the younger and older groups.

Standards Australia's work on producing a standard for protective headgear for cricket focuses separately on faceguards. The standard specifies requirements for faceguards to be attached to cricket helmets to mitigate the effects of a blow to the face by a ball. The standard includes construction, testing and labelling requirements.

8.1.5 Helmets with visors to protect against dental injuries

Dental injuries resulting from cricket have not been well documented. Nethertheless, the Victorian Cricket Association, recently launched a campaign aimed at preventing dental injuries in cricket by the use of helmets with visors (Hewson, 1995). The launch was based on the concerns of the Victorian Cricket Association, data from VISS and concerns of the Australian Dental Association (Hewson, 1996). It was indicated at this launch that one quarter of all sports-related dental trauma injuries were as a result of cricketing injuries (Hewson, 1995). The education campaign was aimed predominantly at school children, who despite the fact that full helmets were usually available to them in kits, were reluctant to use them. The promotional activities included the production of posters showing Dean Jones, a well known cricketer, holding the full facial helmet with the statement " teeth don't get a second innings" (Australian Dental Association, undated). Unfortunately, however, due to a lack of funds, evaluation of this campaign did not occur.

8.2 Body protectors

There is a large array of protective equipment available for the batters and wicket keepers, to prevent ball collision injuries. Such equipment includes helmets with visors, leg guards, thigh pads, chest protectors, forearm guards, batting gloves and genital protectors (batting boxes).

Direct injuries to the batter occur from the cricket ball. The batter's hands, toes and feet are particularly vulnerable, while soft tissue injuries around the upper leg, abdomen and testicles (male cricketers) can be severe. It is for this reason that body padding is required by the batter. As indicated by Stretch (1993), finger injuries keep occurring despite the use of protective gloves. This suggests that equipment manufacturers may need to increase the protection offered by the batting glove. Although uncommon, injury has occurred to the upper hand from the bat handle (Belliappa & Barton, 1991). A batter's feet are also vulnerable to injury from being struck by a ball and a light batting shoe to promote quick running speed may offer little protection against a cricket ball impact (Corrigan, 1984; Crisp & King, 1994). Corrigan (1984) concluded that fractures to the ribs are not uncommon in the batter and a death from a blow over the heart has been recorded.

Wicket keepers can suffer a great deal of trauma, especially when on the receiving end of a fast bowler. In the past, a wicket keeper's gloves offered little protection. Today they are reported to have better padding and have webbing between the fingers and thumb (Corrigan, 1984). Protective inner gloves and taping are also worn to considerable benefit. Injury, however, may still occur.

Fielders can also suffer from direct blows from the ball in much the same way as the batter, particularly those in the in-field. Another collision-type injury which can occur is when the fielder runs or slides into the boundary fence to stop a 'four' or 'six'. For example, Corrigan (1984) describes three fielders who ruptured their spleen when, attempting to catch a field ball and landed heavily on their side.

Although the above injuries have been reported to occur there is no indication as to whether or not protective equipment was in use at the time of injury. In reviewing the literature of cricket countermeasures, no formal evidence for the benefit of body padding in reducing injury was identified using pre and post intervention methods (Hrysomallis, 1996a).

Similarly, Hrysomallis (1996a) was also unable to identify reports to suggest leg guards, commonly known as pads, provide adequate protection against impact injuries to the lower leg and knee.

The shock absorption of cricket leg guards and batting gloves was investigated by Hrysomallis (1996b). The aim of the study was to investigate factors (including thickness, construction, price, temperature and humidity) which may influence the shock absorption capabilities of protective cricket equipment and its ability to conform to British Standards 6183 (currently under revision). Eleven adult leg guards (including two wicket keeper leg guards) and 11 batting gloves were assessed. The leg guards were found to offer adequate impact resistance around the shin and ankle. Six leg guards, however, did not meet the requirements for repeated drops on the knee roll, particularly in conditions of high temperature and humidity. There were significant correlations between peak deceleration and knee roll thickness and shin padding thickness. Of the batting gloves, two did not meet the standards and many gloves had gaps in the padding. Price was not an indicator of protection offered by either the leg guard or the batting glove. Higher temperature and humidity resulted in more protective equipment failing to meet the Standard and, as expected, construction and pad thickness significantly influenced shock absorption ability.

8.3 Recommendations for further research, development and implementation

- Standards for helmets should be refined and promoted.
- Batters should wear cricket helmets and faceguards that conform to Standards.
- Other cricket players such as fielders, should also wear protective headgear.
- Helmets with face shields should be worn by batters, wicket keepers and other in-fielders in order to reduce face injuries.
- Cricketing heroes should be encouraged to wear helmets as an example to younger players.
- Investigations should be made into the advantages and disadvantages of development of a multi purpose helmet. Ideally this would have a removable shield and could be used for cycling, horse riding, roller skating as well as cricket and other sports.
- Epidemiological research into the incidence of eye injuries and associated factors should be undertaken.
- Epidemiological research into the incidence of dental injuries and associated factors should be undertaken.
- Mouthguards should be used by wicketkeepers and batters at all times, to prevent dental injuries.

- Body protection is essential for all batters and should include gloves, leg pads and boxes. Forearm guards may also be worn.
- The protective performance of padding needs to be determined and improved, if found to be lacking.
- Gloves and other protective gear should be worn for informal games as well as for competition.
- The development and careful evaluation of new innovations such as low impact cricket balls should be encouraged.
- Developmental research needs to be conducted into cricket bat handle design that can reduce the impact to upper hand and limit compression of fingers during ball impacts

9. OVERALL INJURY PREVENTION

9.1 Warm-up/conditioning programs

Good stretching programs before and after play along with comprehensive conditioning and technique programmes before and during the season are considered to be very important for conditioning a player's body to help prevent injury (Ross, 1996b). Non-elite cricketers may believe that conditioning in preparation for cricket season is not important. The mentality that skill alone will determine a cricketer's fate still prevails (Payne et al., 1987). Perhaps the lack of research into the role of fitness and cricket performance is a major reason for this attitude. There have been no specific evaluations of the role of warm-up and conditioning programs for preventing cricket injuries.

Laboratory studies have demonstrated that the mechanical properties of connective tissues can be altered in response to loading and temperature variations which can bring about changes in joint range of motion (Woo et al., 1990). In reviewing the literature, Best and Garrett (1993) claimed that warm-up prior to exercise, particularly before exhaustive exercise, will help to reduce the incidence and severity of musculoskeletal injuries.

Conditioning programs should involve exercises that develop flexibility, endurance and strength. Flexibility (stretching) will help players to avoid painful pulls to tendons such as the hamstrings, endurance will help players to last through games without becoming exhausted and straining out-of-shape muscles, and strengthening in the off and regular seasons will help players bodies cope with playing in all games during the season (Croce, 1987).

Particular reference must be made to the fast bowler, who, as already stated has a strong chance of suffering from back pain. It has also been discussed in Section 7.5.3 how muscle strength and flexibility are important influences on the probability of suffering back pain.

Crisp (1989) conducted an overview of preventive measures in cricket. He indicated that cricketers should not throw the ball long distances until the shoulder was thoroughly warm and flexible. Likewise, he recommended that bowlers should be given warning before being brought on to bowl in order to warm up. Furthermore, batters should be kept warm and stretched as they wait to go into bat.

The Australian Sports Medicine Federation recommends warm-up for all child cricketers as an essential part of injury prevention. They suggest that a cricketer should complete 5-10 minutes of warm-up before commencement, along with stretching after warm-up and play (Australian Sports Medicine Federation, undated).

In the current coaching manual produced by the Australian Cricket Association, it is recommended that at least 10 minutes of physical warm-up take place prior to a match or practice, along with at least 5 minutes of cooling-down activity at the conclusion of play or training (Australian Cricket Board, undated).

9.1.1 Recommendations for further research, development and implementation

- More research into the role of warm-up as an injury prevention measure for cricket is needed.
- Research should be undertaken into the benefits of different types of warming-up, cooling-down and stretching practices.
- Research into the optimal duration and frequency of warm-up should be undertaken.
- Information about warm-up, cool-down and stretching techniques should be developed and widely promoted to improve specific knowledge of techniques.

9.2 Environmental conditions

Outdoor cricket is played on an oval field of flat grass ranging in size from about 90-150 meters across. In the centre of the field is the pitch, a prepared rectangle of concrete or closely mown and rolled grass on a hard patch of earth. Given this playing environment, it is not surprising that factors such as playing surface and weather can contribute to the risk of injury.

9.2.1 Weather

Summer in Australia means cricket for many people. However, summer in Australia also means sunburn and an increased risk of skin cancer, dehydration, heat exhaustion and heat stroke.

No specific evidence of preventive measures in regard to climate-related cricket injuries were identified by this review. Suggestions for injury prevention have been based on general thermoregualtion recommendations, such as wearing appropriate clothing, using sunscreens, maintaining hydration and by undergoing a process of acclimatisation. Given the playing environment it is not possible to promote adequate shade (ie. trees or shade structures).

It must be noted, however, that cricketers are required, in general, to wear shirts, trousers and a hat if so desired. These are also usually white which does not absorb heat to the same extent as other colours. At state and international level, cricketers are supplied with both a wide brim and a standard cap as part of their uniform for the season (Ross, 1996b). International level cricketers are often seen with white zinc cream covering their nose, cheeks and even lips. The use of sunscreen is, however, not mandatory, although sun protection is provided in change rooms for all players (Ross, 1996b). Given the extreme temperature and time of play (usually anything between 10am-5pm), a greater awareness of these issues needs to be addressed.

Payne et al., (1987) suggested that when playing in hot or humid conditions the medium pace bowler should alternate four minutes of bowling and four minutes of standing still on the boundary. Given a bowler's continual energetic and strenuous activity and batters who may control the strike for a number of overs with many singles being scored and then stand at the non-striker end for an undue period of time at high temperatures, dehydration has to be considered a serious possibility (Payne et al. 1987).

"Successful coaching: the Aussie way", indicates that players who are unfit or overweight are more susceptible to heat illness (Australian Cricket Board, undated).

Coaches and cricketers need to be aware of symptoms of heat stress such as cramps, headache, dizziness and uncharacteristic lack of co-ordination. Regular intake of fluids is required to reduce the risk of heat illness and maintain physical and mental performance. Thus it is recommended that one or two glasses of plain water is drunk 45 minutes prior to the event, continual opportunities to drink are provided during play and regular consumption after play is continued to replace fluid loss (Australian Cricket Board, undated).

The Australian Sports Medicine Federation recommend that to prevent dehydration in cricketers aged 15 years, 300-400mls of water should be consumed 45 minutes before play. During the event 150-200mls of water should be consumed every 15-20 minutes and after the event water consumption should continue until urination is normal. For the average 10 year old these levels are reduced to half (Australian Sports Medicine Federation, undated).

It may also occasionally rain during play. At this time the pitch may be covered, so as to prevent it from becoming sticky. An over-wet pitch may allow the ball to bounce erratically endangering the bowler (Ross, 1996b).

The umpires are responsible for determining play during wet weather. The umpire may consider the ground as unfit for play when it is wet or slippery and depriving the bowlers of a reasonable foothold, the fieldsmen, other than the deep fielders of the power of free movement, or the batters of the ability to play their strokes or to run between wickets (Victorian Cricket Association, 1995). Play should not be suspended merely because the grass and the ball are wet and slippery (Victorian Cricket Association, 1995).

9.2.2 Surface

A bowler’s run-up and a batter’s normal run between wickets can produce impact forces from two to three times their body weight. For this reason the surface is an important factor to consider when reviewing the nature and incidence of cricketing injuries. Studies have looked at the ground force impacts but they have not sufficiently investigated this in relation to the surface, nor have they looked at other hazards of the playing environment. The Australian Institute of Sport (AIS), however, is currently looking at the back foot and front foot ground reaction forces on varying surfaces that may provide appropriate substitutes for current pitches and examining the compression of landing area (Ross, 1996b). The Australian wicket is quite hard compared with that of other places (e.g. Britain), and this may be associated with more injuries in Australia (Ross, 1996b).

Cricketers rely heavily on the quality of the whole playing field, not just specifically the pitch. Without doubt, the pressure upon those charged with the responsibility of maintaining cricket surfaces has never been greater (McAuliffe & Gibbs, 1993). The New Zealand Turf Culture Institute has responded to requests from several national sports bodies to establish a national performance testing system (McAuliffe & Gibbs, 1993). The performance testing system is a precise and scientific means of monitoring the standard of the construction and maintenance of the cricket field. Specific details are given on outfield dimensions, levelness and speed; pitch levelness and pace; surface and sub-surface hardness; and ball rebound resilience.

Also important in regard to the playing field is the need to eliminate the possibility of injury occurring due to potholes, sprinkler pop-ups and even the occurrence of rubbish on the field. This is particularly the case in situations were the field is used for more than one sporting activity and can often be used as a social arena. The pitch, as the centre of play, must also be carefully prepared to ensure it is flat and smooth. As the pitch is often covered for the Australian Rules Football season, maintenance is difficult, and at the commencement of the Cricket season excessive sand may remain on the pitch, which could contribute to falls and injury.

9.2.3 Recommendations for further research, development and implementation

- Drinking water should be provided at all cricketing events.
- Cricketers should ensure they drink adequate water.
- Appropriate drink breaks should be developed, which benefit the player rather than the game. This could include the possibility of having a drink person on field.
- Cricketers should always use a broad spectrum sunscreen and wear a hat and/or sunglasses if appropriate.
- Cricket events should not be planned for times when there is a likelihood of hot, humid conditions or much rain. Whenever possible, such events should also be cancelled if such weather conditions eventuate.
- Cricket fields should be regularly checked and maintained to eliminate hazards such as potholes, sprinkler pop-ups, loose debris, rubbish etc.

9.3 Footwear

Appropriate footwear is relevant to all cricketers and especially bowlers, who during a day's play will run 5 to 6 km and walk 10 to 15 km while suffering ground reaction forces of 4 to 9 times body weight. (Elliott et al., 1986; Mason et al., 1989 Hardcastle, 1991)

In a study of 82 high performance young male fast bowlers with a mean age of 16.8 years, the height of the longitudinal arch of the foot was significantly related to back injury (Elliott et al., 1995). Bowlers with a low arch (i.e. flat feet) were more likely to develop a stress fracture in the lumbar vertebrae. It may be possible that a foot with a low arch may not be capable of absorbing the high forces at front foot impact as effectively as a foot with a medium or high arch (Elliott et al., 1995). This suggests a role for improved footwear design or the use of orthotics. No literature was found on the use of orthotics specifically for cricket.

A batter's feet are also vulnerable to injury from being struck by a ball, and a light batting shoe which may promote quick running speed may offer little protection against a cricket ball impact (Corrigan, 1984; Crisp & King, 1995; Hrysomallis, 1996a). No literature describing the selection and the benefits of well designed cricket footwear could be found.

Despite a lack of research data, shoe companies such as Puma continue to run campaigns emphasising that their footwear will prevent injury. *"What's the first thing you pack in your kit for protection against serious injury? Gloves? Helmets? Protector? Or shoes? If shoes aren't at the top of your list they should be"* (Sports Weekly, 1996).

Kennedy and Fitzgerald (undated) recommend that sorbanthane (a trademark artificial shock absorbent substance used extensively in the inner soles of running shoes) in shoes should be used.

Currently, the Commonwealth Bank Cricket Academy in association with the AIS, along with doctors, paediatricians and coaches are meeting to develop a new bowling shoe aimed at reducing the stress on fast bowlers in association with a sporting footwear company and a leading podiatrist (Done, 1996). The prototype is almost ready for production, it is low-cut but firm in the front around the ankle and the sprig formation is different (Marsh, 1996).

9.3.1 Recommendations for further research, development and implementation

- Further development of appropriate footwear for cricketers should be undertaken, both for fast bowlers and other players.
- Guidelines on how to select an appropriate cricket shoe need to be prepared
- Cricketers, particularly fast bowlers, with flat feet or high arches should seek professional advice about shoe design and orthotic use.

9.4 Modified rules and children

When it comes to sports performance, children must not be thought of as little adults (Stanitski, 1988). Significant differences exist between child and adult athletes, and those interested in injury prevention must understand the difference (Meyers, 1993). Growth and maturation rates even amongst children, demonstrate marked variability along with concomitant gains in coordination and strength, flexibility, and endurance (Stanitski, 1988).

Section 5 showed that cricket injuries do occur in children. Greater emphasis needs to focused on prevention among children as opposed to adults.

The Australian Cricket Board has developed a modified version of cricket called Kanga cricket. Kanga cricket has been developed for primary aged children, to offer them an introduction to the game and a chance to develop skills before progressing to more competitive levels. Kanga cricket is played with a specially designed soft ball, which is similar to a hard cricket ball yet eliminates the need for protective equipment and reduces the likelihood of injury. The bats and stumps are of light weight moulded plastic and smaller in size. Kanga cricket also has rules about short pitch deliveries.

Kanga cricket is likely to prevent injuries in three ways (Ross, 1996b):

- skill level is increased, before players reach high risk level of play
- a softer ball (which is softer than a tennis ball) is used and this decreases the likelihood of injury from impact
- bounce (ie. ball) evasion is taught as an essential skill of the game.

The Australian Cricket Board in conjunction with teachers and education development officers, has produced a lesson plan book for Kanga Cricket (Australian Cricket Board, 1995b). This document outlines the correct methods of bowling, catching, fielding, throwing, running between wickets and includes a recommended lesson format which includes 5-10 minutes of warm-up.

The Australian Sports Medicine Federation's 'Guidelines for safety in children's sport: cricket', outlines recommendations for warm-up, stretching and equipment use along with guidelines for the fast bowler (Australian Sports Medicine Federation, undated).

A progression from Kanga Cricket, called VicHit has been developed by the Victorian Cricket Association and adopted by the Australian Cricket Board. In 1995 there was 48 registered VicHit programmes throughout Victoria (Victorian Cricket Association, 1995a). By gradually introducing and developing more formal skills, children's entry skills are far greater when they start to play with a harder ball and so they are more likely to: catch the ball more effectively, avoid the ball more effectively when batting, and bowl the ball onto the pitch, all of which help to avoid injury (Ross, 1996a).

As already shown, stress fractures in the lumbar region of the spine in adolescents are not uncommon. It is important therefore that children and adolescents are taught the correct bowling technique as well as giving themselves appropriate rest periods (Sections 7).

9.4.1 Recommendations for further research, development and implementation

- Children should be encouraged to play with softer than standard bats and balls as in kanga cricket.
- Children should be encouraged to play Kanga cricket as a means of developing cricket skills.
- Child and adolescent fast bowlers should be taught correct bowling techniques and procedures, including limiting the number of overs and taking appropriate rest periods.

9.5 Education and coaching

Instruction clinics on proper cricketing techniques currently occur in school-related organisations. Guidelines have been produced by the Australian Cricket Board to aid in school education programs, particularly on Kanga Cricket and the progression to the VicHit program.

The large number of recreational players, however, makes this source of information impractical for community based teams. As a result those in coaching positions need to be fully educated about the correct techniques. Currently it is not mandatory for cricket coaches to be accredited. Coaches of cricket teams who are accredited, need to have this qualification reviewed every four years. As cricket is developing in terms of preventing injury, particularly fast bowling injuries, coaches need to be aware of the current status of knowledge. This may mean disregarding old coaching manuals or beliefs, for new ones, for the benefit of the cricketer (Ross, 1996b). For example, fast bowlers should no longer be made to only attempt the perfect side-on position (Ross, 1996b). Each individual bowler will have their own natural positioning, while mixed bowling techniques should be discouraged. It is important to assess the bowlers' natural position and adapt them to either a side-on or front-on position, whichever is more suitable.

The Australian Cricket Board, has recently produced a manual entitled 'Successful cricket coaching: the Aussie way' (Australian Cricket Board, undated). This manual outlines all areas of the game, with easy to follow recommendations on technique, injury prevention and first aid, as well as indicating what the role of the coach should be and the best way in which to educate players.

9.5.1 Recommendations for further research, development and implementation

- Coach should undergo regular re-accreditation.
- Coach education schemes should be updated regularly to ensure they provide the most up to date information.
- Instruction clinics for the wider community should be developed and widely disseminated.
- Education resources for informal cricket need to be developed and disseminated.

9.6 First aid and rehabilitation

Injuries need to be properly managed to restrict the possibility of further damage. Overall, the treatment goals are pain relief, promotion of healing, decreased inflammation, and a return to functional and sports activities as soon as possible.

In the majority of collision type injuries and some overuse injuries this will mean rest, ice, compression, elevation and referral (RICER).

The manual "Successful coaching: the Aussie way", indicates that while a coach cannot be expected to be a medical specialist, an understanding of fundamental first aid is seen as a part of a good coach's responsibility (Australian Cricket Board, undated). Procedural guidelines in the assessment and immediate management of injuries refers to two actions "STOP" and "RICED".

- S Stop the player from participating
- Stop the game if necessary
- T Talk to the injured player
- O Observe, whilst talking, the players personality and injury site
- P Prevent further injury by either getting help in a severe injury case, carry out the RICED regime in less severe cases and in minor cases continue play, with a few words of support and encouragement.

"RICED" refers to the sequence rest, ice, compression and elevation, diagnosis, which should be implemented for any ligament sprains, muscle strains and muscle haematomas; in fact any bumps and bruises which occur in sport. This manual also indicates how and why these actions should be undertaken, stating that the first 48 hours are vital in the effective management of any soft tissue injury. Injuries managed effectively in the first 48 hours can reduce the time spent on the sidelines by up to 6 weeks

The Australian Sports Medicine Federation's 'Guidelines for safety in children's sport: cricket', outline what to do in the case of an injury, referring to 'PRICED'. Prevent further injury, rest injury, ice, compression, elevation and diagnosis.

Returning to play too early after injury can make the player susceptible to further injury (Australian Cricket Board, undated). The coach should ensure that the risk of further injury is reduced. Concentration on muscle stretching exercise routines before play will assist in preventing injury.

According to Powell et al. (1986), a previous injury may be more likely to re-occur because the original tissue, or the injury may not have healed completely. This leads to the conclusion that complete and controlled rehabilitation of an injury needs to be achieved, and sensible preventive precautions taken, before the person begins to play cricket again.

A rehabilitation programme cannot be regarded as having been completed 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.

9.6.1 Recommendations for further research, development and implementation

- Cricketers should seek prompt attention for their cricketing injuries from a person with first aid qualifications.
- Organisers of events should ensure that there are qualified first aid personnel at all events.
- Injured cricketers should ensure that they allow enough time for adequate rehabilitation before returning to their pre-injury level of activity.
- Research into the effects of rehabilitation programs for cricketers needs to be undertaken.

10. INDOOR CRICKET

Indoor cricket is a relatively new game in Australian, commencing in about 1970. It has grown quickly in popularity with approximately 8% of the Australian population over the age of 16 participating in the sport (Brian Sweeney and Associates, 1991).

The game is played on a field of 12m x 28m, which is surrounded by netting on the walls and roof, with all-purpose carpet floor coverings and a ball similar to a tennis ball covered in leather. The speed of play is much more intense in indoor cricket, given the confined space in which six fielders, a bowler, a wicket keeper and two batters must play.

Given the confined space, along with advertisements for the game stating that there is no need for protective devices to be worn (a marketing strategy which was adopted to widen the appeal of the game (Coroneo, 1985)), it is hardly surprising that injuries occur.

Routley and Valuri (1993) reported that 25% of all adult cricket injuries presenting to emergency departments in Victoria resulted from indoor cricket. Indoor cricket players were found to be twice as likely to be injured by strain or overexertion and were more likely to be injured by a fall than outdoor players who were more likely to slip or be hit by the ball.

Forward (1988) looked at the site and nature of injury in 64 patients who presented with indoor cricket injuries at the Royal Perth Hospital, Australia. Of these, 72% were fielding at the time of injury, 17% were batting, 11% were wicket keeping and no-one who was bowling was injured. This is contrary to the figures for outdoor cricket, where fielders are at the least risk of injury. Of the injuries that resulted, 43% occurred to the upper limbs, 28% to lower limbs, 20% to the eye or face, while other areas accounted for 9% of all injuries.

Accident Compensation Corporation statistics in New Zealand showed that in 1987, 520 injuries received in indoor cricket were compensated. The knee accounted for 20% of injuries, the face 17% of injuries and the fingers and thumbs 15% of injuries (Sadleir and Horne, 1990).

In a report specifically investigating 33 finger and thumb injuries in indoor cricket over two seasons, it was found that most injuries were sustained by the wicket keeper (33%), while fielders sustained (24%) and both batters and those playing the backstumps sustained 9% (Sadleir and Horne, 1990). The mechanism of injury was found to be due to the impact of the ball directly on to the tip of the finger (33%), followed by hyperextension (21%). The remainder were due to a variety of reasons.

In a report focusing on eye injury, Auburn (1990) found that 30% of all sports injuries to the eye seen at Wellington Hospital were due to indoor cricket, the highest incidence rate for all sports presented. All of these injuries resulted from the cricket ball striking the eye.

10.1 Recommendations for further research, development and implementation

Although this is only a brief review it seems evident that indoor cricket injuries are generally similar to those of the outdoor game, despite the fact that the most common site of injury and position of play may differ. It is recommended, therefore, that those involved in the game of indoor cricket take the incidence and nature of injury more seriously and work to prevent unnecessary injury.

- Current regulations indicate that batting gloves must be worn in both hands by each batter, the wicket keeper has the option of wearing none, one or two suitable gloves, while players fielding may wear suitable protective equipment, however gloves may not be worn by the fielder unless special circumstances arise were the player has been injured previously. It is thus recommended that regulations be emplaced and enforced.

- that all fielders, batters and wicket keepers wear a pair of gloves.

- that protective helmets with visors be worn by both batters and wicket keepers.

- protective body equipment by batters.

11. SUMMARY AND CONCLUSIONS

This report has discussed the full range of injury prevention activities for preventing cricket injuries. Recommendations for futher countermeasure research, development and implementation have been based on the review presented here as well as discussions with experts acknowledged in this report.

Many of the recommended countermeasures have yet to be proven to be effective and more attention to controlled studies "in the field" are needed. More effort directed to basic scientific studies to better understand the biomechanics of cricket, the mechanisms of injury and the role of various risk factors in causation are also required. Indeed, the evidence for the effectiveness of certain countermeasures such as warming-up, shoe design, limited overs and body padding remains equivocal.

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

- Improved data collection about the occurrence of cricket injuries and their associated factors needs to be developed and maintained.
- Data about injuries and their associated factors in recreational cricketers needs to be collected.
- Data collections should conform to guidelines for sports injury surveillance being developed and promoted nationally.
- Information about preventing cricket injuries should be disseminated widely through cricketing broadcasts, cricket equipment points of sale, cricketing magazines and more general magazines.
- Guidelines for minimum safety requirements for cricket events (including the need for mobile phones, telephone contacts, first aid kits, etc) should be developed and widely disseminated.

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APPENDIX 1: Incidence of injury per body part

APPENDIX 1: Incidence of injury per body part

Author	Finch et al., 1995	Finch et al., 1995	Routley, 1991	Routley and Valuri, 1993	Stretch, 1993	Stretch, 1995
data source	Australian emergency department presentations	Australian emergency department presentations	Victorian emergency department presentations	Victorian emergency department presentations	Self-report questionnaire. Club & provincial players. South Africa	Self-report questionnaire. Schoolboy cricketers. South Africa
n	3846	1945	257	398	183	116
population	adults	children	children	adults	adults	teenagers
head	16.6%	44.2%		3%	9.1% (head/neck/face)	19.3% (head/neck/face)
face			40%	23%		
upper extremities	32.6%	33.9%			34.1%	24.6%
arm			18%	15%		
hand/finger			18%	21%		
lower extremities	22.8%	15.5%			37.5%	22.8%
leg			7.5%	20%		
foot			10.5%	6%		
trunk	4.2%	3.2%		7%	19.3%	33.3%
other	4.1%	3.2%	6%	5%		

APPENDIX 2: Biomechanics of fast bowling

APPENDIX 2: Biomechanics of fast bowling

Note: Population groups were all young elite fast bowlers (0 = mean of total group, 1 = no radiological features, 2 and 3 = radiological features. For exact definitions refer to original study).

		Elliott et al., (1986)	Elliott et al., (1992)				Elliott et al. (1993)		Foster et al., (1989)
Phase	**Aspect**								
	population	0	1	2	3	0	1	2	0
general	n=	15	3	6	11	20	15	9	82
	age	20.8	16.6	17.4	18.7	17.9	13.5	14	16.8
	height (m)	1.85	186.9	184.8	182.0	185.4	1.57	1.59	
	mass (kg)	85.1	68.7	75.6	79.1	78.6	51	51	
	Sum skinfolds (mm)	10.75	32.7	35.3	43.2	42.7	32.9	36.1	
	sit and reach (cm)	11	8.0	4.5	10.5	6.1	1.9	1.8	
	Sit-ups (60s)	43	38	41.5	38.0	39.4	34.5	40.0	
run-up to BFI	back foot angle at back foot impact	306.3	250	293	296	292.5	287	294	
	approach velocity (ms^{-1})	4.6	4.8	4.5	5.1	5.1	4.5	4.6	4.95
	shoulder alignment at back foot impact	231.8	179	206	197	206.3	212.9	218.6	219
	back foot impact (vertical)								
	back foot impact (horizontal)		3.0	3.0	2.5	2.9			
delivery	stride length (m)	1.29	1.55	1.51	1.64	1.60	1.3	1.4	
	stride length/height (%)	70	81	79	86	86	83	88	
	stride alignment (cm)	3.2	-1.1	-1.1	-1.1	-1.1			
	Minimum shoulder alignment		179	181	193	187.4	194	188.6	
	shoulder alignment at front foot impact	217	188	199	203	200.8	209.3	198.8	202.7
	shoulder alignment counter-rotation						18.9	30	
	front foot impact (vertical)	4.1	6.4	6.3	5.9	6.4	4.8	1.4	5.43
	front foot impact (horizontal)	-1.6	-1.9	-2.1	-2.0	-1.9	-2.1	-2.6	-2.45
release	shoulder alignment at release	300	124	116	123	122	319.1	312.0	
	release height	2.2	2.04	2.12	2.13	2.11			
	ball velocity	30.6	32.3	30.9	32.6	31.7	24.4	24.8	
	height of release/height	1.16	-19.3	-13.2	-4.9	-10.9			
	front foot impact at release (vertical)	1.0	110	113	114	114	119	114	
	back foot impact at release (horizontal)	0.1							

APPENDIX 3: Incidence of radiological features

APPENDIX 3: Incidence of radiological features

Author	Population	n	mean age	Bony abnormalities	Spondylolytic incidences	Spondylolisthesis	Spondylolysis	Pedicle sclerosis	Disk degeneration	Pars defect	Pain
NORMAL POPULATION											
Roache & Rowe (1952)						5-7%					
Fredrickson et al. (1984)							4%				
Hensinger (1989)							6%				
Bell (1992)							5%				
CRICKET POPULATION											
Elliott et al. (1993)	elite young fast bowlers	24	13.7						21-58%		
Elliott et al. (1992)	W.A. young fast bowlers squad	20	17.9	55%	45%	25%	20%	30%	30%		69%
Annear (1992)	Former state fast bowlers	20	48.3			10%	20%	25%	70%	20-45%	
Hardcastle et al. (1991)	WA, U19 fast bowling squad					19%	39%		58%	58%	
Foster et al. (1989)	elite young fast bowlers	82	16.8		11%						27%
Mackay & Keech (1988)	Vic & NSW U19 & U17 squads	72								20%	
Payne (1987)	A-grade fast bowlers			50%							
Burnett et al. (1996)	elite young fast bowlers	19	13.6						58%		53%
Walker et al. (1996)	elite young fast bowlers	56							34%		14%