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RUGBYSMART: THE DEVELOPMENT, DELIVERY AND EVALUATION OF A NATIONWIDE INJURY PREVENTION PROGRAMME

Kenneth L Quarrie

PhD

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Kenneth L Quarrie

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Approved by Will Hopkins

Chairman of Supervisory Committee

School of Sport and Recreation

Abstract

This thesis represents my research work relating to rugby union from 2000 to 2007. During this time I was the Manager of Injury Prevention and Research for the New Zealand Rugby Union (NZRU). The main priorities of this role were to increase understanding of risk factors for rugby injury, to implement preventive measures, and to assess the effect of those preventive measures. The thesis is presented as a series of peer-reviewed, published papers.

A key concern of the NZRU when I undertook the role was to decrease the number and severity of spinal cord injuries occurring in New Zealand rugby. The first paper is a review of literature of rugby union injuries to the cervical spine and spinal cord. This paper was published in Sports Medicine, and the knowledge derived therefrom formed an important element in RugbySmart, which was the nationwide injury prevention partnership between the NZRU and ACC. The second paper, which was published in the British Medical Journal, outlines the effect of RugbySmart on serious spinal injuries in New Zealand. Eight spinal injuries occurred in New Zealand in 2001-2005, whereas the predicted number based on previous incidence was 19 (relative rate 0.46, 95% confidence interval 0.19 to 1.14). The main reason for the decline was a decrease in the number of injuries from scrums, from a predicted number of nine only one was observed (relative rate 0.11; 0.02 to 0.74).

Injury prevention initiatives in New Zealand appear to have been successful in areas beyond spinal injuries. The third paper deals with the effect of RugbySmart in general. RugbySmart was associated with a decrease in injury claims per 100,000 players in most areas the programme targeted; the programme had negligible impact on non-targeted injury sites. The decrease in injury claims numbers was supported by results from player behaviour surveys pre- and post-RugbySmart. There was an increase in safe behaviour in the contact situations of tackle, scrum and ruck technique. The fourth paper, which was published in the British Journal of Sports Medicine, examines the effect of mandating mouthguard usage on mouthguard wearing rates and ACC dental injury claim rates. The self reported rate of mouthguard use was 67% of player-weeks in 1993 and 93% in 2003. A total of 2644 claims was reported in 1995. There was a 43% (90% confidence interval 39% to 46%) reduction in dental claims from 1995 to 2003. On the reasonable assumption that the number of players and player-matches remained constant throughout the study period, the relative rate of injury claims for non-wearers versus wearers was 4.6 (90% confidence interval 3.8 to 5.6).

In New Zealand the tackle is the facet of play associated number of injuries, and over the past decade tackles have overtaken scrums as the cause of the greatest proportion of spinal injuries. To address the lack of knowledge regarding risk factors for injuries in the tackle, a large scale study of tackles in professional rugby matches was undertaken. In 434 matches, over 140,000 tackles were coded. The impact of the tackle was the most common cause of injury, and the head was the most common site, but an important mechanism of lower limb injuries was loading with the weight of another player. Rates of replacement increased with increasing player speed. The resulting paper was published in the American Journal of Sports Medicine.

A commonly cited model of injury causation in sport posits that risk factors for injury can be considered as those related to the athlete (intrinsic) and those related to the activity (extrinsic). To examine the extent to which the activities comprising rugby matches at the international level has changed over time the first match in each Bledisloe Cup series from 1972 to 2004 was coded. Increases in passes, tackles, rucks, tries, and ball-in-play time were associated with the advent of professionalism, whereas there were reductions in the numbers of lineouts, mauls, kicks in play, and in mean participation time per player. Noteworthy time trends were an increase in the number of rucks and a decrease in the number of scrums. With the advent of professionalism, players have become heavier and backs have become taller.

A number of articles written to communicate injury prevention messages to rugby union coaches, players and administrators are presented as appendices, along with two peer reviewed papers that closely relate to the thesis, but which I excluded from the thesis proper.

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signed: 

Date: 30 April, 2008

Candidate contributions to co-authored papers

Chapter	Contribution (%)
Chapter 1 – Rugby union injuries to the cervical spine and spinal cord	85%
Chapter 2 – Effect of nationwide injury prevention programme on serious spinal injuries in New Zealand rugby union: ecological study	70%
Chapter 3 – Evaluation of RugbySmart: a rugby union community injury prevention programme	40%
Chapter 4 – An evaluation of mouthguard requirements and dental injuries in New Zealand rugby union	70%
Chapter 5 – Tackle injuries in professional rugby union	75%
Chapter 6 - Changes in player characteristics and match activities in Bledisloe Cup rugby union from 1972 to 2004	80%

Preface

Personal Background

How was it that I came to be undertaking PhD studies in the epidemiology and prevention of injuries in rugby union? In the following paragraphs I will attempt to highlight a few points that, subjectively at least, have made an impression on me as having shaped my decision to pursue a PhD in this field.

Rugby union is widely considered the national sport of New Zealand, owing to the large number of participants and the high media profile the sport enjoys. As is the case with many New Zealanders, the sport of rugby union has played a major role in my life. Childhood memories of playing barefoot on frosty King Country mornings (where the highlight was often the orange at half-time!) mingle with those in which my mother presented the scrap book she had adoringly kept of my father's representative rugby career ("…and he once played against *The Springboks*.."). I remember being woken at 2:00 am and travelling with my father to friends places to watch early morning live broadcasts of All Blacks test matches on ‘colour TV’. Celebrating the successes and commiserating with the failures of the All Blacks was, in my family, of greater significance than religion, and probably of greater importance than the political happenings of the day. My hero was Sid Going, and I spent many hours on the family lawn practicing passing and kicking, convinced, with the certitude that belongs to childhood, that I was going to be an All Black when I grew up.

Other rugby memories that stick in my mind include the day in 1984 I was picked up after school by my mother, who broke the news to me that a friend with whom I used to play tennis had been injured in a collapsed scrum, and was not expected to walk again. I recall wandering around the playing field at Carisbrook on a beautiful Dunedin afternoon sometime in 1990 or 1991, confused as to why we were playing the 'wrong' team. I had been concussed, and couldn't work out why the team we were supposed to be playing seemed to have suddenly been substituted for one that was completely different. The three week stand-down rule for concussion was easily circumvented, for the most part by not disclosing the injury. I sustained several concussions during my rugby playing days, along with an injury to the cervical spine that kept me out of play for a couple of seasons. The emphasis of the game itself was on winning. The jubilation in the changing shed following a win contrasted sharply with the despair of a loss. Either occasion presented a justification for drinking heavily. ‘Take no prisoners’ and ‘put your body on the line’ were favourite phrases of some of the coaches I had. The legacy of New Zealand’s experiences in the World Wars cast a long shadow, and were obvious in terms of the language, the beliefs and the behaviours of coaches and players. The concepts of mateship, and never letting the side down regardless of the personal cost, were strongly imbued. Playing on when injured was widely regarded as heroic, and served the purpose of not allowing any rivals for one’s position in the starting fifteen to have an opportunity to ‘shine’. Getting 'jabs' from a local doctor to allow me to play a game with a hairline crack to the pelvic bone was part of my student rugby experience, and was done mainly for this reason.

Epidemiology and Prevention of Rugby Injuries in New Zealand

Rugby injuries in New Zealand had been identified by the medical community as an issue requiring attention since at least the early 1980s. Opinion pieces and case-reports expressing concern about the incidence of spinal injuries and safety issues in scrums [5, 16] and studies investigating injury incidence [7, 17] began appearing in the sports medicine and general medical literature from around this period. A number of experimental safety variations to the laws of the game regarding scrummaging were implemented in the mid-1980s. These included changes to binding and the engagement process in grades below senior, and the limiting of pushing to 1.5 m. Unfortunately, the effectiveness of these measures was not monitored.

Rugby results in higher costs to the Accident Compensation Corporation (ACC), New Zealand’s tax-payer funded injury insurance scheme, than any other sport. By the early 1990s, ACC and the Health Research Council (HRC) of New Zealand had decided that rugby injuries represented a problem of sufficient significance to warrant investment in a large-scale prospective study. The Rugby Injury and Performance Project [37] (RIPP) – one of the first major prospective cohort studies of sports injuries that permitted quantification of risk factors using epidemiologic methodology– was jointly funded by the HRC and ACC, and was carried out by the Injury Prevention Research Unit at the University of Otago Medical School. Following the completion of a Master's degree in Physical Education (the topic was the biomechanics of rugby scrummaging [32]) in 1993, I was employed as a co-investigator on RIPP. Fifteen papers [1, 3, 4, 10, 19, 20, 22, 24, 27, 28, 31, 34, 37-39] have been published from the data collected during RIPP, of which I took the lead on five [22, 24, 27, 28, 31], and contributed as an author on a further four [1, 18, 20, 34]. These papers covered the anthropometric and physical performance characteristics of players, alcohol use patterns within the cohort, and risk factors for injuries. The Injury Prevention Research Unit presented a stimulating scientific environment. Debates and discussions about methods, critical evaluation of papers and an introduction to the statistical methods appropriate to longitudinal studies excited my enthusiasm for the research process.

Tackling Rugby Injury [34], a document produced that was based on the findings of RIPP contained a number of injury prevention recommendations. Some of these recommendations were introduced between 1995 and 2000 via a partnership between the Injury Prevention Research Unit of the University of Otago, the New Zealand Rugby Union, and ACC. The group set up to oversee the introduction of the injury prevention measures was called the Tackling Rugby Injury Panel (TRIP). I was an author on Tackling Rugby Injury, but I was not directly involved with TRIP.

The effectiveness of few (if any) of the injury prevention measures implemented under Tackling Rugby Injury on rugby injury incidence had been evaluated at the time RugbySmart began in 2001 [6]. Another factor that stimulated action with respect to injury prevention was the release to the NZRU in 1996 of a paper documenting spinal injury numbers in New Zealand rugby union from 1976 to 1996 [2]. The findings prompted the NZRU to institute compulsory safety seminars, which focused on safety in the scrum and tackle. Prior to 1996 such seminars had been mooted within TRIP, but were not adopted by the NZRU on the grounds they would be too difficult to develop and run nationally.

RugbySmart

In 2000, the NZRU, in conjunction with ACC, made the decision to create the position of NZRU Injury Prevention Manager. The purpose of this position was to act as a driver for the development, implementation and evaluation of a nationwide injury control programme in New Zealand rugby. The NZRU/ACC injury control programme was subsequently entitled RugbySmart. The term RugbySmart was a catch-all for the injury control partnership programme launched by the NZRU and ACC. RugbySmart covered injury surveillance, risk factor identification, the development and implementation of preventive measures for rugby injury, and evaluation of the success of the interventions. The aim of RugbySmart was to systematically reduce the incidence and severity of rugby injuries to players in New Zealand.

I was fortunate enough to be appointed to the position of NZRU Injury Prevention manager, and it soon became clear to me that there was an opportunity to lead research that I believed would be worthy of consideration for a PhD. I approached Professor Will Hopkins, and enquired whether he would be prepared to accept me as a PhD student under his supervision, a request to which he agreed. My PhD does not consist of a single research problem. Rather, it comprises a series of published papers, all of which deal with aspects of rugby that relate to the risks and activities of the sport. The rationale and overarching structure that links the thesis into a coherent whole are explained in the sections below.

Control and Prevention of Sports Injuries – The Epidemiological Approach

Although its origins can arguably be traced to Galen's studies of gladiatorial injuries in Ancient Rome, sports injury epidemiology is a relatively recent field of scientific enquiry. Textbook accounts of the history of injury epidemiology in general have highlighted that developments in transport technology during the mid-20th century, and the consequent morbidity and mortality associated with these activities, contributed to the realization that patterns of injury in populations were similar in many ways to disease processes. The application of epidemiological methods to studying injuries in populations then arose [13]. The classical approach to investigating the epidemiology of disease looked at interactions among the host, the agent and the environment as a model for identifying factors important in the development of diseases within populations. Modification of this idea to link transfer of energy to being the agent of injuries was undertaken by Gibson [12]and further developed by Haddon in a 1980 paper [14]. Energy in its various forms has the potential to result in injury if it is transferred from the environment to a person in an amount or form that leads to the body tissues being unable to maintain their structural or functional integrity [15]. Common examples are electrical, mechanical, thermal and physical energy transfer as manifested in electrocution, motor vehicle crashes, burns and rugby tackles respectively.

Thus, under the classical approach to injury epidemiology, the injuries sustained in rugby union by a given population of players reflects the frequency and nature of the energy transfers that occur during participation and the ability of the body structures/tissues of the participants to withstand those energy transfers when they occur. The participant (usually a player, but occasionally a referee or spectator) is the host, the activities that comprise matches and training, and the location in which they occur, are the environment, and the transfer of energy associated with the activities is the agent. In a simplistic sense, injury prevention in rugby is basic. If people avoid the energy transfers associated with the sport, they will not sustain rugby injuries. People can choose to participate in rugby or not – for those who don't the risk of receiving rugby injuries is zero. Likewise, risk of specific injuries such as those associated with tackles, could be reduced by law changes that reduced the number of tackles. Not all potential injury prevention measures can be implemented, however. When the position of NZRU Injury Prevention Manager was created, one of the performance measures for the position was to 'eliminate permanently disabling spinal injuries *within the context of a contact sport*' (italics added by me). It was made clear that although efforts to improve safety in the sport would be taken, removing key elements of the sport such as tackles and scrums would be unacceptable, short of such a change being forced upon the administrators of the sport via legislation or similar regulatory measures. Given that some people wish to play rugby, and that players generally wish to avoid injury (especially severe injuries), the challenge was to help develop and implement injury control measures that would be both effective in reducing injury and acceptable to participants.

RugbySmart and the 'Sequence of Sports Injury Prevention'

A widely cited approach to implementing and evaluating injury prevention measures is the 'Public Health Approach' [33]. Within the sporting context, the Public Health Approach has been popularised by van Mechelen, and is commonly known as van Mechelen's 'Sequence of Sports Injury Prevention' model [35]. The Public Health Approach/Sequence of Sports Injury Prevention model provided a loose framework within which work on RugbySmart was undertaken. Subsequent attempts [8, 36] to build upon the sequence of sports injury prevention model had not been published when RugbySmart began, hence I will use the model as it was when the planning for RugbySmart began (Figure 1). In the following section I will place the various aspects of the RugbySmart programme within the context of the sequence of prevention model, and also highlight the pieces of work that I have chosen for the thesis within the same model, on the understanding it may be helpful to readers of the thesis if I were to provide such a breakdown.

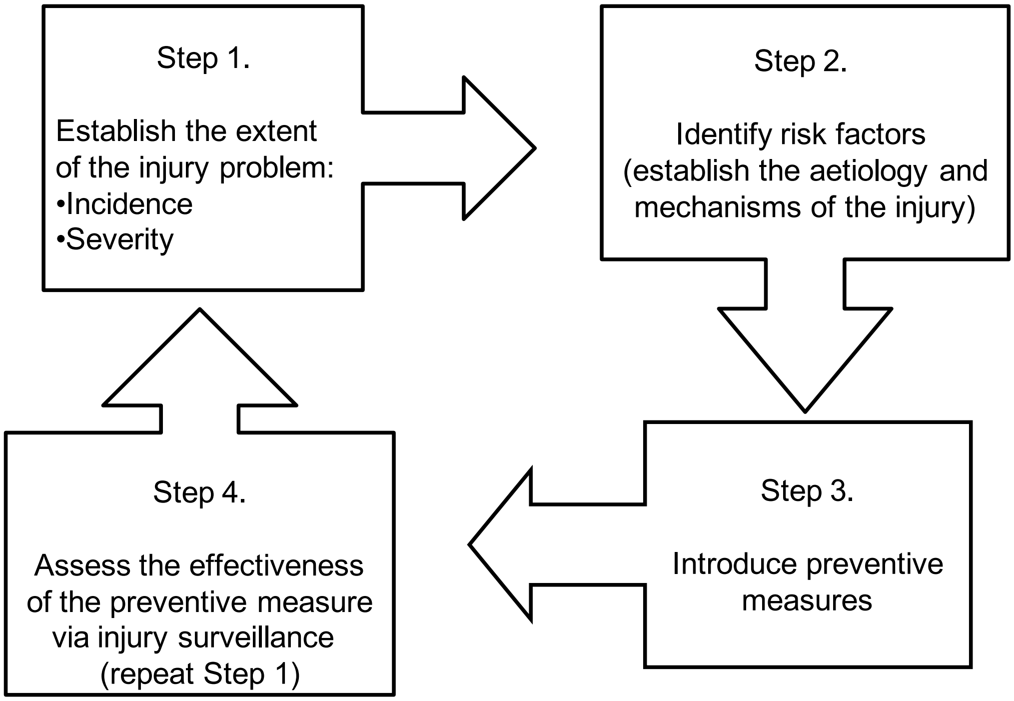

Figure 1. The sequence of sports injury prevention [35] .

Although RugbySmart was conceived as a nationwide injury prevention programme in which it was desired that all rugby injuries be mitigated, in practice various aspects of the injury problem were targeted. Those types of injury or risk factors for injury that were perceived by the NZRU and ACC to be of particular importance received the greatest amount of focus. As outlined in the section highlighting some of the history of injury prevention in New Zealand, RugbySmart did not appear out of a vacuum. RugbySmart followed on from considerable work on identifying incidence and risk factors in New Zealand rugby over the preceding two decades. As a result of the previous work, when the RugbySmart programme began, not all components of rugby injury were at the same 'Step' in van Mechelen's sequence of prevention. Taking the liberty of adding 'develop' to Step 3, table 1 shows various components of the rugby injury problem in New Zealand, where they lay in terms of the sequence of prevention at the inception of RugbySmart, and the steps of the sequence of prevention completed as part of the thesis.

Table 1: Application of the 'Sequence of Sports Injury Prevention' with respect to the thesis.

	Steps in the 'Sequence of Sports Injury Prevention"			
Injury Component	1: Establish incidence and severity	2: Identify risk factors	3: Develop and introduce preventive measures	4: Assess the effectiveness of the preventive measures
Spinal Injury Epidemiology				
Status pre RugbySmart	Incidence of spinal cord injury in New Zealand rugby union was unclear. A case-series study published in 1997 published incident numbers from 1976 to 1996 but lacked player numbers to establish incidence	Injury mechanisms and risk factors identified from case-reports and case-series studies – lack of systematic review	Compulsory seminars based on 'best practice' were being run in New Zealand	Not undertaken at the inception of RugbySmart
Aspects in thesis	**Chapter 2** Incidence obtained via development of NZRU player registration database and ACC claim data	**Chapter 1** Review of literature of rugby injuries to the cervical spine and spinal cord:**.**	**Chapter 2** Introduction of RugbySmart (2001). Evaluation of effect of RugbySmart on spinal injury incidence in New Zealand Rugby.	**Chapter 2** Introduction of RugbySmart (2001). Evaluation of effect of RugbySmart on spinal injury incidence in New Zealand Rugby.

General injury epidemiology: Sites/type/severity of injury in matches and training – beginning of RugbySmart	Estimates published via RIPP	Many risk factors identified via RIPP	Injury prevention measures developed in Tackling Rugby Injury Some preventive measures implemented/some not	Attempted but unable to be completed in the Tackling Rugby Injury Project
General injury epidemiology: Sites/type/severity of injury in matches and training - aspects covered in thesis	**Chapter 3** Incidence obtained via development of NZRU player registration database and ACC claim data	**Appendix 1** A paper in the Appendix on which I am first author, RIPP VI deals directly with Step 2, and was published after RugbySmart began. It does not, however, form one of the papers of the thesis proper.	**Chapter 3** RugbySmart implemented in 2001. Evaluation of knowledge, attitudes, behaviours and injury rates (collected via ACC claims)	**Chapter 3** RugbySmart implemented in 2001. Evaluation of knowledge, attitudes, behaviours and injury rates (collected via ACC claims)
Dental injury epidemiology- beginning of RugbySmart	Estimates of incidence published in RIPP (1993) and obtained from IPRU Rugby Injury Surveillance Project	Mouthguards identified as a potential protective factor (RIPP and other studies)	Endorsement of compulsory mouthguard wearing in Tackling Rugby Injury Measure implemented in Under 19 Grades in 1997 All grades in 1998	Had not been undertaken when RugbySmart began

Dental injury epidemiology - aspect covered in thesis				**Chapter 4** Evaluation of the impact of compulsory mouthguard wearing on dental injury rates in New Zealand rugby players
Tackle injuries - beginning of RugbySmart	Estimates of incidence published in RIPP and other studies	Little work identifying particular characteristics of tackles that modified the risk to players. None which examined non-injury tackles to establish risks per tackle as well as per player exposure	Tackle injury technique and progressive build-up to contact situations incorporated into RugbySmart based on expert (coach) knowledge	None undertaken when RugbySmart began

Tackle injuries - aspect covered in thesis		**Chapter 5** Identification and quantification of risk factors in the tackle situation		
Temporal trends in match activities and player characteristics - beginning of RugbySmart	None published when RugbySmart began.	None published when RugbySmart began	A number of law changes and changes to the sport were introduced over the period 1972-2004.	None undertaken when RugbySmart began
Temporal trends in match activities and player characteristics – aspects covered in thesis		**Chapter 6** Law changes and professionalism were evaluated in terms of their effect on extrinsic and intrinsic risk factors: match activities and player stature and body mass.		

A major focus for the NZRU when the position of Injury Prevention Manager was first established was on decreasing the incidence of spinal injuries, especially those relating to permanent disablement. Spinal injuries are the only aspect of rugby injury contained in the thesis in which all four steps of the sequence of prevention model are dealt with directly through work that was done in RugbySmart. At the time RugbySmart began, ACC data on permanently disabling spinal injuries in rugby had been collected, but no long-term trends resulting from analysis of the data had been published. In addition, prior to 1998, there was no systematic method of counting rugby player numbers in New Zealand, which meant that injury data were limited to reports of incident numbers, rather than incident rates of injury [26].

Chapter 1 of the thesis consists of a review and synthesis of literature dealing with rugby injuries to the cervical spine and spinal cord. The stated objective of the position of NZRU Injury Prevention Manager was to achieve zero serious (i.e. permanently disabling) injuries. In an effort to understand what was known about risk factors for spinal cord injuries in rugby, I searched the scientific literature. There had been no previous published review of serious spinal injuries in rugby union. The report that I produced was provided by the NZRU Board to the Chairman of the International Rugby Board. As a result I was invited to present to the General Council of the IRB on the topic of spinal injury prevention in Copenhagen in March, 2001. Following the presentation, I undertook to rework the report I had written into a manuscript to be submitted to the Journal "Sports Medicine". The resulting paper was published in Sports Medicine in 2002 [23].

We conducted an ecologic study of spinal injuries resulting from rugby in New Zealand covering the period 1976 to 2005. The introduction of RugbySmart in New Zealand coincided with a marked reduction in rugby-related spinal injuries, and a paper on the issue was subsequently published in the British Medical Journal in June 2007. The BMJ devoted the cover of the issue in which our paper appeared to the topic of making rugby safer, and an editorial accompanied the paper. The BMJ paper, which received international media exposure, forms Chapter 2 of the PhD [26].

RugbySmart seminars focus on educating rugby participants about physical conditioning, injury management and safe techniques in the contact phases of rugby. From the inception of the programme, I attempted to provide evidence-based best practice information to coaches, referees and players. Chapter 3, which has been accepted for publication in the Journal of Science and Medicine in Sport, consists of an evaluation of the impact of RugbySmart on shoulder, leg, knee, and ankle injuries and non-disabling injuries of the neck/spine 11 and also examines changes in coach and player knowledge and behaviour regarding injuries and the prevention thereof. RugbySmart was associated with a decrease in injury claims per 100,000 players per year for most body sites the programme targeted; the programme had negligible impact on non-targeted injury sites. This is the only paper that is part of the PhD on which I am not the lead author.

Another ecologic study, published in the British Journal of Sports Medicine in 2005, provided evidence of the benefit of wearing mouthguards in rugby and is included in the PhD as Chapter 4 [25]. Based on estimates of mouthguard-wearing rates and claim numbers to ACC we estimated that non-wearers of mouthguards sustained injuries at 4.6 times the rate of wearers, and that the introduction of compulsory mouthguard wearing was associated with a decrease in incidence of dental claims of 43% from 1995 to 2003.

When RugbySmart began, the tackle situation had been identified as a major risk factor for rugby injuries in general [3] as well as for spinal injuries [23]. Despite this, the complexity of the tackle situation meant that there was a dearth of information about what particular aspects of the tackle situation were associated with changes in risk. Studies of injuries in tackles that been undertaken had a number of limitations. Firstly, information about those tackles that did not result in injury had not been provided. Relative rates of injury for specific types of tackle were thus not available. In addition, the relatively small scale of the case-series studies presented to date meant that a large degree of uncertainty remained with respect to the inciting events, or mechanisms, of tackles that result in injury. To overcome these limitations, I designed and managed a large-scale study of tackle injuries that collected data about all tackles that occurred in selected professional rugby matches, rather than just those that resulted in injury. Video data were used to examine the specific circumstances of tackle injuries and medical records provided information about the site, type and severity of injuries. A paper entitled 'Tackle Injuries in Professional Rugby Union' was published in the American Journal of Sports Medicine. This paper is Chapter 5 in the PhD [30].

Current models of sports injury emphasize the multifactorial nature of injury causes. Factors related to the person, and factors related to the sport are conceived of modifying the risk of participants, who then become injured if subjected to an 'inciting event' that results in a transfer of energy above the biomechanical limits of the body structures [21]. Studies of injury epidemiology have focused on identifying risk factors for the sport – for example, in the rugby situation, the tackle has been identified as a risk factor for injury. Little attention, however, has been paid to the way in which the extrinsic risks associated with activities in a particular sport may change over time. To examine the extent to which potential risk factors evolved in rugby I developed a project that tracked the match activities and player size in the first match in each Bledisloe Cup series contested between Australia and New Zealand from 1972 to 2004. This period contained the change of rugby at international level from an amateur to a professional sport. A paper detailing the changes was published in the Journal of Sports Sciences in 2007. This, the sixth and final paper in the PhD [29] also resulted in media reports in New Zealand and abroad.

Several other peer-reviewed papers on aspects of rugby injury and performance were completed through the period of the PhD. In 2001 a paper from the RIPP study describing intrinsic risk factors for rugby players was published in the British Journal of Sports Medicine [22] (Appendix 1). This was the first published paper in rugby injury epidemiology to apply multivariate generalized linear models to the study of risk factors for rugby injury. I also wrote a number of articles on injury prevention and the RugbySmart programme for the NZRU coaching magazine (Appendices 2-6). In 2007, the IRB produced a consensus statement on injury definitions for studies of rugby injuries (Appendix 7). I was a co-author on this paper, and provided considerable input [9]. The consensus statement was published simultaneously in the British Journal of Sports Medicine and the Clinical Journal of Sport Medicine.

Acknowledgements

Many people have assisted with or contributed to this PhD. I would like to formally acknowledge the outstanding mentorship and guidance provided by Professor Will Hopkins, my primary supervisor. Will's fanatic attention to making sure things are 'right' has been a source of both frustration and inspiration to me. Many analyses have been run, re-run, and re-run again. Many sentences have been written, edited, deleted, re-written and edited again. Such is the process of learning to do research. Thank you Will.

Thanks also to Professor Patria Hume, who was my secondary supervisor, and Dr Stephen Marshall, my external advisor. As well as contributing to two of the papers in the PhD, Patria has provided much needed administrative guidance, which complemented Will in an area that is not his favourite.

The NZRU have been very supportive of my desire to undertake PhD studies. In addition to assisting with fees, they have provided financial support for the study of tackle injuries, and time to complete analyses and papers. The contribution of ACC staff, and especially Simon Gianotti, with respect to RugbySmart and the papers derived therefrom also deserves special mention.

I also want to thank my co-authors on the various papers that make up this PhD. Research has, for me, always been a collaborative process, and I believe that, in the field of sports injury epidemiology, working with people and discussing ideas as a paper develops generally leads to a better outcome than work done by flying solo.

Finally, thanks to my friends and family, without whose support and encouragement I would not have completed this work. Although it is unfair to those who I don't mention by name, there are some people I need to identify. First, my parents Lincoln and Gwen, for their unwavering belief in me. Secondly, my wife Eva, who has sacrificed her time to allow me to continue with PhD studies. Eva has encouraged, cajoled, and at times, demanded, that I complete what I started. I can't thank her enough.

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THESIS CHAPTER 1

RUGBY UNION INJURIES TO THE CERVICAL SPINE AND SPINAL CORD

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Rugby Union Injuries to the Cervical Spine and Spinal Cord

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Contents

Abstract

Injuries to the cervical spine are among the most serious injuries occurring as a result of participation in rugby. Outcomes of such injuries range from complete recovery to death, depending on the degree of spinal cord damage sustained. Much information has been gained regarding the mechanisms and frequency of such injuries, from case reports and case series studies. The most commonly reported mechanism of injury has been hyperflexion of the cervical spine, resulting in fracture dislocation of C4-C5 or C5-C6. Tracking both the trends of incidence of spinal injuries, and the effectiveness of injury prevention initiatives has proved difficult because of a lack of properly conducted epidemiological studies.

Within the constraints of the research published to date, it appears that hookers and props have been at disproportionate risk of cervical spine injury, predominantly because of injuries sustained during scrummaging. While the scrum was the phase of play most commonly associated with spinal injuries throughout the 1980s in most rugby playing countries, there has been a trend through the 1990s of an increasing proportion of spinal injuries occurring in the tackle situation. The majority of injuries have occurred early in the season, when grounds tend to be harder, and players are lacking both practice and physical conditioning for the physical contact phases of the sport.

A number of injury prevention measures have been launched, including changes to the laws of the game regarding scrummaging, and education programmes aimed at enforcing safe techniques and eliminating illegal play. Calls for case-registers and effective epidemiological studies have been made by researchers and physicians in most countries where rugby is widespread, but it appears to be only recently that definite steps have been made towards this goal. Well-designed epidemiological studies will be able to provide more accurate information about potential risk factors for injury such as age, grade, position, gender and ethnicity. Research into the long-term effects of participation in rugby on the integrity of the spinal column is warranted.

1. Background

Injuries to the spinal cord (along with serious head injuries) are among the most tragic of injuries that can result from participation in Rugby Union football (rugby). While these injuries are rare in terms of number of occurrences per player exposure, they can have devastating consequences for both the individual and their community. Depending on the degree of spinal cord damage sustained, a range of outcomes are possible. Long-term morbidity caused by injuries of the cervical spine varies from no permanent impairment to tetraplegia and, in approximately 5 to 10% of cases, death.[1] The association between participation in rugby and these injuries has been noted for over a century, as evidenced by the report from *The Times* of London from November 1869 shown in figure 1.[2]

Reports from a number of rugby playing countries suggest that the frequency of this type of injury increased during the 1970s and 1980s, and the topic has received greater attention in the medical literature over the past 30 years than was the case prior to that time. To date, most research papers regarding spinal injuries in rugby have been either case reports or case series studies.

A variety of injury prevention measures have been implemented both internationally by the International Rugby Board (IRB) and at the national level by the administrative bodies of the sport in specific countries. These have included:

- Alterations to the laws of the game (such as changes in scrum engagement procedures).
- Education of players, referees and coaches regarding both 'safe techniques' in the contact

phases of the game and guidelines for injury management and first-aid.

The extent to which these injury prevention initiatives have impacted on the incidence of spinal injuries occurring within rugby is debatable. At present, we are unable to determine the extent to which differences in patterns of injury observed over time and across nations reflect true differences in incidence or whether they are more closely associated with variability in data collection. Measuring the incidence of these injuries and evaluating the effectiveness of interventions designed to reduce their incidence has been hampered by many factors, including:

- A lack of systematic recording of the number and severity of spinal injuries occurring in rugby. This includes lack of standardised definitions of both injury and recovery of function with respect to time. In some countries, there is neither central collation of spinal injuries that occur during participation in Rugby Union nor differentiation between spinal injuries sustained in Rugby Union and other football codes.
- Lack of consistent information about the spectrum of severity of spinal injuries associated with potential risk factors (e.g. tackles).

"...in the course of a severe scrimmage a young gentleman named Lomax got down, with his head bent under his chest, and in this position was trampled on by many of the players. He was picked up insensible, and, with the exception of short intervals of consciousness, he has remained so until the present time... If he survives, (which is still doubtful!), it is feared he will be a cripple for life."
The Times, 27 November, 1869.

Fig. 1. A report of a spinal injury in rugby from the 1800s (cited in Dunning and Sheard[2]).

- Lack of information regarding the number of participants per year in the various rugby playing countries.
- Lack of information about exposure to rugby by participants at the various levels of the sport (e.g. differences in average number of games played per year by grade).
- Lack of measurement of the changing patterns of activity within the game itself as a consequence of law changes and the continuing evolution of the sport.

Within sports injury epidemiology, these problems are not unique to rugby or to spinal injury. Problems of consistency with respect to injury definition and data collection have been noted across a variety of sports and types of injuries.[3] Calls by researchers from New Zealand,[1] South Africa,[4,5] Australia,[6,7] Canada,[8] and the UK[9,10] for the setting up of proper surveillance methods (including assessment of the population at risk) have been made. Noakes and Jakoet,[11] for example, stated that 'the international community of doctors involved in rugby must convince rugby administrators in all countries to set up epidemiologically valid surveys of injuries. Until they do, there will not be enough accurate data to support change.'

The purposes of this review are:

- To summarise the information regarding risks for spinal injury within rugby that have been presented in the scientific and medical literature.
- To attempt to place this information within an epidemiological framework to facilitate the setting up of data collections systems that will yield information from which to make informed decisions regarding injury prevention strategies.

2. Search Strategies

A variety of search strategies were used in an attempt to source all relevant literature with respect to cervical spinal injuries in rugby. Searches of the Medline, Sport Discus and the CARL Uncover databases were undertaken. In each case the search conditions were:

- inclusion of the words 'rugby' and ('spine' or 'spinal') in the title of the article for Sport Discus, and in the title or the abstract for Medline
- year of publication in the period 1970 to 2001 inclusive
- the language of the article was English.

In addition, articles in which the level of the publication was 'basic' were excluded from the Sport Discus search. The reference lists of all review articles identified by the above searches were examined to determine whether important references may have been missed or were not included in the electronic databases. A database of sports injury literature that has been compiled over the period 1993 to 2000 by the Injury Prevention Research Unit of the University of Otago, New Zealand, was also searched. Internet searches using the metasearch engines 'Metacrawler' and 'Dogpile' were undertaken to allow for the possibility that other relevant literature may have been available, but was not included in the above databases. One book containing information relevant to the topic was located via the web metasearch.[12,13]

The Sport Discus search returned 43 articles that met the search criteria, Medline returned 73, and Carl Uncover returned 21. The search of the Injury Prevention Research Unit database returned 59 references. Once duplicates (107) were identified, the remaining set of articles was checked for relevance against the purposes of the review as outlined in the introduction. Twenty-eight articles were rejected as a result of this check. Two articles could not be obtained, and abstracts only were available for three. Fifteen papers on topics related to risk factors for rugby injury in general were also referred to.

3. Risk Factors for Spinal Injury

Grouping risk factors into those associated primarily with participation in rugby (extrinsic factors), and those associated mainly with the player (intrinsic factors) provides a convenient structure for considering the literature.[3] Figure 2 provides a list of potential risk factors. As will be immediately apparent, many of these are related to each other to some extent (e.g. grade and age). Evaluation of the current state of knowledge regarding a number of these factors is presented in section 4. Many of them have yet to be the subject of research investigations with respect to their association with spinal injury in rugby. While there are likely to be risk factors that are not included in the figure, investigating the relative importance and strength of interactions of the risk factors below would pro-

Extrinsic risk factors	**Player-related risk factors**
Laws of the game	Grade
Illegal play	Age/maturity
Match play	Experience
Phase of play:	Position
tackle	Skill
scrum	Anthropometric characteristics (body size and shape)
ruck/maul	Congenital abnormalities of the spine
Time of season	Physiological characteristics (e.g. strength/anaerobic fitness)
Environmental conditions:	Psychological characteristics
temperature	Information processing ability
climatic conditions	Visual acuity
Pitch hardness/condition	Impairment – fatigue/alcohol/drugs
Referee's control of the game	Occupation
Coaches' instructions to players	Gender
Importance of game:	Ethnic origin
trials/finals etc.	

Fig. 2. Potential risk factors for rugby-related spinal injuries.

vide a good start to gaining enough knowledge with which to make sound recommendations about how to reduce the risk of spinal injury faced by players.

4. Player-Related (Intrinsic) Risk Factors

4.1 Age, Grade and Experience

As might be expected from studies that have used varying data collection methods and definitions of injury, there are conflicting opinions as to the relative importance of age, grade and experience on the risk of spinal injuries. Early reports of spinal injuries suggested that schoolboys were at greater risk of sustaining spinal injuries than players at senior level.[14-17] A number of these reports[16-23] were either small-scale case series reports or letters to the editors of scientific journals by those working in spinal units expressing concern about apparent increases in the number of schoolboys that had sustained spinal injuries.[9,14,24,25] An explanation posited for why this might be the case included lack of maturity of the skeletal and ligamentous systems, leading to greater ease of fracture and dislocation injuries than was the case as players matured.[14] Bottini et al.[26] found that in Argentina, young players were at higher risk of sustaining muscular or ligament injuries to the cervical column than were senior players. While noting that this was 'worrisome', the authors did not suggest what factors might have contributed to this finding. Milburn[27] also suggested that older and more experienced players were better able to both cope with the forces generated in the scrum and maintain their body positions during engagement, thereby preserving the integrity of the scrum. Other points of concern included the fact that schoolboys were often not at liberty to choose whether they participated in the sport, and a lack of insurance against injury for schoolboys.[28]

While some larger scale studies still reported that young players make up a large proportion of all spinally injured players,[29] most have reported that the incidence of injuries tends to be higher among adults, and especially those at higher grades. This pattern has been observed for other types of injury.[26,30-32] Kew et al.[4] found that adults sustained 69% of spinal injuries in a South African survey. They suggested that the ratio of schoolboy players to adults in the area from which their injured players were drawn was likely to be between 5 : 1 and 10 : 1. From these ratios, they calculated that adult players faced a risk that was 10 to 12 times higher than that of schoolboys. Reasons suggested for this included greater size and physical strength of players (thus making them capable of generating greater forces during impacts) and greater aggression. Hence, Kew et al.[4] suggested that high levels of skill and fitness, far from protecting against these injuries, might actually make injury more likely. Armour et al.[1] concurred that in New Zealand, when taking into consideration the number of players at risk, senior club games produced the highest concentration of injuries. Similar sentiments have recently been expressed by Silver,[33] who has worked with spinal injuries among rugby players in England since the 1950s. Both Armour et al.,[1] and Silver and Stewart[34] referred to the fiercely competitive nature of the game at this level as being a factor that potentially places players at higher risk.

A number of these studies, while reporting the proportion of schoolboy and adult players injured, provided insufficient information from which to determine the average age of the players in their sample. The average age of 273 injured players over a number of case series studies was 22.8 years.[1,6,16,29,35-37] As with the proportion of players injured at various ages, the findings regarding the relationship between age and severity of injury, or prognosis for recovery are varied. An Australian study found no relationship between age and the degree of subsequent recovery.[6] In New Zealand,[1] the proportion of players who were confined to wheelchairs was greater among the youngest 32 players (41%) than in the oldest 32 (25%). This difference was not statistically significant. In contrast to this, in South Africa, between 1990 and 1997,[38] 61% of schoolboys made total or near complete recovery from injury, compared with 28% among adult players.

A 20-year review of spinal injuries among players in Wales revealed that there appeared to be a relationship between the level of injury (i.e. the cervical vertebrae at which the lesion occurred) and the player's age.[35] The evidence presented suggests that as players age, the lower part of the neck becomes more prone to damage. A similar proportion of young players sustained serious spinal cord injury (75%) to the total group (70%). While their injuries appeared to be of the same type as those of the older players, they tended to be higher up the neck. Whether this pattern of level of injury relating to age is in any way related to the degenerative changes observed in the spine of older players presented in samples of players from New Zealand,[39] South Africa[40] and France[41] is unknown.

A finding that has been reported somewhat more consistently is that of the increased risk faced by players when a 'mismatch' between skill, experience and/or strength occurs among players within the scrum – especially those in the front row. Silver,[14] in a letter commenting on this phenomenon, suggested that mismatches between schoolboys and adults were particularly risky, and that it was not always the players in the weaker team that were injured. A submission made by Silver[42] regarding prevention methods included advice that schoolboys should not be permitted to play for, or against adult teams. This recommendation was among several adopted, and Silver and Stewart[34] reported several years later that injuries occurring because of 'mismatches' had ceased within the area over which they were collecting information. Similar concerns have been voiced regarding variations in maturational level of adolescents of the same chronological age, and the increased risk that may be faced by players who are less physically mature.[43] In Australia, Taylor and Coolican[6] reported that 'a discrepancy in strength between opposing front rows may contribute to scrum instability. However, in the players' judgement of the relative strength of the front rows, injuries occurred with almost equal frequency to players in both the adjudged stronger or weaker front rows.'

Wetzler and coworkers[36] stated that 15% of spinal injuries recorded in the US 'involved a documented mismatch in experience and size between collegiate and men's clubs'. This proportion rose to 25% when the scrum was the only phase of play considered.[44] Wetzler et al.[44] clearly outlined the relative shortage of practice facilities for scrummaging in the US and that players were often learning to scrummage during games. Lack of coaching and practice facilities were postulated to contribute to a lack of coordination among the players within the scrum, lessening the ability of the scrum to coordinate the engagement and maintain control during game situations. They felt that forwards in America were generally bigger and had greater strength than those in other nations. The higher incidence of scrum injuries seen in the US was attributed to these factors, in conjunction with relatively inexperience players. It was not known how many 'experienced' players were injured due to the inclusion of inexperienced players in the front row positions.[36,44]

4.2 Gender

As with grade, there is little evidence about the extent to which gender is a risk factor for spinal injuries in rugby. Case reports of female rugby players sustaining spinal injuries have appeared in the literature,[1,36] but in the absence of any reliable estimates of numbers of women players in the game, relative risks by gender are unable to be assessed.

4.3 Ethnicity

Little attention has been given to whether ethnicity is a risk factor for spinal injury among rugby players. Compared with other countries, a high rate of spinal cord injuries among Fijian players has been reported from within the Fiji Islands.[45] At present, the lack of epidemiological evidence precludes conclusions from being drawn about whether the higher rate is primarily related to the style of the game (e.g. extrinsic factors), or whether there are any intrinsic differences in risk among ethnic groups. Within New Zealand, the Maori population were found to have a higher rate of spinal cord injury from all causes than New Zealand Europeans.[46] Whether this pattern is also found within contact sports such as rugby is worthy of further examination.

4.4 Position

A consistent finding from case series analyses has been the high proportion of injuries sustained by players in the front row (table I). Approximately 30% of the spinal injuries reported were sustained by hookers (who represent 6% of all players by number). This over-representation was due almost entirely to increased risk during the set scrum. Props were the second most frequently injured position, sustaining about 17% of rugby-related spinal injuries.

Few reports identified which positions in the backline were most frequently injured. The highest proportion of spinal injuries to backs has been reported in South Africa.[4] Of 34 spinal injuries to backs, 41% were sustained by the midfield backs – the second five-eighths and centre positions, 26% by the inside backs (half back and first five-eighths), 23% by the two wings, and 9% by the fullback. The tackle situation was the phase of play in which backs sustained the majority of their spinal injuries (84%), with the remainder from the ruck/maul.

Williams and McKibbin[35] similarly found that of seven spinal injuries to backs, centres were the most frequently injured (57%), with the remainder sustained by inside backs (43%). Williams and McKibbin[35] reported no injuries to wings or fullbacks. In New Zealand, the position of 21 backs injured from 1976 to 2000 was obtained by combining the reports of Armour et al.,[1] and Palairet and Xiong.[37] Seven injuries (33%) were sustained by both midfield and inside backs, six (28%) by wings and one (4%) by a fullback. As was the case in South Africa, the majority of injuries to backs occurred in the tackle situation, and from 1996 onward, all of the injuries to backs reported by Palairet and Xiong[37] were sustained during tackles. Percentages are not corrected for number of players within each position in the team.

4.4.1 Laws of the Game Relating to Training and Experience of Front-Row Players

The importance of having experienced players in the front row of the scrum has been incorporated within the laws of the game.[47] Law 3.5, which deals with this matter states: *Suitably trained and experienced players in the front row:*

- [table II] *indicates the numbers of suitably trained and experienced players for the front row when nominating different numbers of players.*
- Each player in the front row and the potential replacement must be suitably trained and experienced.
- The replacement of a front row forward may come from suitably trained and experienced players who started the match or from the nominated replacements.

Table I. Distribution of cervical spinal injuries in rugby by position

Study	Country	Period of study	Hooker n	Hooker %	Prop n	Prop %	Other forward n	Other forward %	Back n	Back %	Unknown n	Unknown %	Total n
Secin et al.[29]	Argentina	1977-1997	9	50.0	1	5.6	4	22.2	4	22.2	0	0.0	18
Taylor and Coolican[6]	Australia	1960-1985	16	43.2	14	37.8	4	10.8	3	8.1	0	0.0	37
Armour et al.[1]	New Zealand	1976-1995	33	27.7	20	16.8	24	20.2	13	10.9	29	24.4	119
Palairet and Xiong[37]	New Zealand	1996-2000	10	28.6	3	8.6	13	37.1	8	22.9	1	2.9	35
Kew et al.[4]	South Africa	1963-1989	14	18.4	7	9.2	21	27.6	34	44.7	0	0.0	76
Wetzler et al.[36]	USA	1970-1994	28	47.5	7	11.9	10	16.9	12	20.3	2	3.4	59
Williams and McKibbin[35]	Wales	1964-1984	3	10.0	10	33.3	9	30.0	7	23.3	1	3.3	30
Total			**113**	**30.2**	**62**	**16.6**	**85**	**22.7**	**81**	**21.7**	**33**	**8.8**	**374**

Table II. Numbers of suitably trained and experienced players for the front row when nominating different numbers of players (adapted from International Rugby Board,[47] with permission)

Number of players	Number of suitably trained and experienced players
15 or less	3 players who can play in the front row
16, 17 or 18	4 players who can play in the front row
19, 20, 21 or 22	5 players who can play in the front row

While this is laudable, it begs the question of what 'suitably trained and experienced' is defined to be. Unless standards are developed by the IRB (or its member nations) for players at various ages/grades, it is likely that what constitutes 'suitable training and experience' will be decided by a court of law.

4.5 Anthropometric and Physiological Characteristics

As with age and experience, a range of views as to the importance of anthropometric characteristics of players with respect to risk of injury have been expressed in the scientific literature. On one extreme, Calcinai[48] stated that 'probably the most important single factor in preventing scrummage injuries is to ensure that player (sic) have an appropriate body-type for the position. Front-row players must have short squat necks and it is a recipe for disaster to ask a player who has a long thin neck to play in the front row.'

By contrast, Armour et al.[1] proposed that in the 'mismanaged' scrum, all builds are equally at risk. They pointed to a number of high-profile New Zealand tight forwards who had recently been forced out of the game through injury, and to one case in particular where an All Black prop sustained a serious neck injury (subluxation of the atlas on the axis). The unanswerable question is whether an injury of this type would have happened much sooner had an individual of less imposing physical characteristics been in the same position and subjected to the same loads. Quarrie et al.[49] found that when position and grade were controlled for, the thinnest 20% of club players (as measured by body mass index) missed a greater amount of playing time during the season (caused by all injuries reported, not just spinal injuries) than their more robust counterparts. A number of studies have identified that the anthropometric characteristics of players vary substantially by position.[50-54] Presumably, players gravitate towards positions in which their particular anthropometric characteristics provide them with a competitive advantage (or at least, do not unduly disadvantage them). While the scientific evidence is sparse, a court case in Australia in 1987[55] resulted in a prosecution against a school for allowing a schoolboy player of 'inappropriate' build to be placed in the front row of a rugby league scrum. Until more information is collected about the effect of physique on risk, it is safer to err on the side of caution and continue to recommend that thin players (or players with long/thin necks) do not take up positions in the front row. The development of prospective studies should help to provide answers to these questions.

4.5.1 Congenital Abnormalities of the Spine

Case reports of players with congenital abnormalities sustaining serious spinal injuries have appeared in both South Africa and New Zealand. Scher[23] initially called for screening of all players over a certain age (30 years), because of the fact that repeated trauma may have caused degenerative changes to their spine, and hence be placing them at greater risk. He subsequently suggested[56] that those with congenital fusion of the spine were particularly at risk of hyperextension injuries of the spine, and that all regular rugby players should undergo a screening x-ray at least once in their careers. It may be worth noting that while hyperextension injuries to the spine occurring in rugby have been reported, they appear to be much less common than either impacts to the top of the head or injuries occurring via hyperflexion and rotation.

The same suggestion for the screening of rugby players has recently been made in New Zealand by Hughes.[57] To summarise the information outlined by Hughes,[57] of 100 cases of rugby-related cervical spine injuries treated at the Burwood Spinal Unit in Christchurch, New Zealand, between 1979 and 1999, 85 had complete records. Examination of the x-rays of these 85 cases revealed that seven players had congenital cervical fusion. This rate (7/85) is much higher than has been reported for congenital fusions in other populations (an average of around 7/1000 from three studies of cadavers). Among the 85 cases, 28 remained tetraplegic. Three of the players who became tetraplegic as a result of their injuries had congenital fusions. Further research regarding the extent to which these conditions predispose rugby players to catastrophic injuries should be conducted. It would be prudent, however, to advise any player who sustains a neck injury beyond a simple muscle strain to obtain a clearance to play from a spinal or orthopaedic specialist prior to recommencing participation in rugby.

Congenital abnormalities of the spine have been extensively researched in American Football, and a series of recommendations regarding the advisability of playing contact sports given a range of conditions exists.[58] The condition for which screening has been recommended in New Zealand rugby (a type II Klippel-Feil fusion – a single level fusion of two vertebrae in the cervical spine) at C3 or below with no neurological symptoms or restricted movement was considered by Torg and Ramsey-Emrhein[58] to present no contraindication to participation in contact or collision sports.

4.5.2 Chronic Conditions/Degenerative Changes of the Spine

Studies showing accelerated degeneration of the cervical spine among front-row forwards have appeared in the medical literature.[39-41] Berge et al.[41] examined the spines of 47 rugby players and 40 age-matched controls by using magnetic resonance imaging (MRI). Of 35 senior and veteran front-row players, a significantly greater proportion (71%) exhibited narrowing of the intervertebral disks than did age-matched controls (17%). A significantly greater proportion of senior and veteran front-row players also had herniated disks (31%) than did controls (3%). Among front-row players, there was an almost total loss of bone marrow in the cervical spine, which was replaced by fibrosis and sclerosis. Among American football players, stenosis of the cervical spine defined as loss of CSF around the cord or in more severe cases as deformation of the spinal cord has been identified as a risk factor for spinal cord injury.[59] This definition of cervical spinal stenosis ('functional' spinal stenosis) cannot be made by bone measurements or ratios, a technique Herzog and associates[60] found had a positive predictive value of only 12%, but requires imaging by MRI, contrast enhanced computed tomography or myelography.

In the data from the National Center for Catastrophic Sports Injury Research between the years 1987 and 2000,[61] no patients with quadriplegia with cervical spine fracture dislocation and functional spinal stenosis recovered completely. This is to be compared with nearly 20% of patients with initial quadriplegia with fracture dislocation who had normal-sized spinal canals who went on to a complete neurologic recovery. During this same time period there were cases of quadriplegia that occurred without fracture dislocation, and in every instance, severe functional spinal stenosis was present. Thus, in the experience of the National Center for Catastrophic Sports Injury Research, cervical spinal stenosis as defined above predisposes the athlete to a worse neurologic outcome when spinal cord injury occurs. The same might be anticipated in rugby, but data examining the relationship between spinal stenosis as measured by MRI and the relationship with injury is lacking.

Berge et al.[41] found that the canal diameter, and the canal-cord ratio of rugby players was lower than that of age-matched controls, and that the condition appeared to worsen with age. Similar differences were found in other measures of degenerative changes, and the extent of the degeneration correlated with age.

The majority of lesions were located in the lower cervical spine, which is the region that Williams and McKibbin[35] found was more commonly injured in older players. The changes were attributed to the repetitive cervical trauma that players experienced throughout their careers. Scher[40] suggested that the risk of spinal cord injury to players would be increased by this type of degeneration, but as yet there is a lack of evidence to substantiate this claim. Presumably, the increased rate of degeneration[39-41] is related to the demands of scrummaging, in which players attempt to twist and buckle their opponents in an attempt to gain an advantage.

A report examining changes to the patterns of the game suggests that primarily because of law changes introduced in 1963, the time spent practising scrummaging, and the use of scrum machines is much greater than was usual before that time. These changes mean that front-row players are subjected to physical pressure and stress for much longer periods than was previously the case.[62]

4.6 Summary of Intrinsic Risk Factors for Spinal Injuries in Rugby

- Research into the relationship between age and both incidence and severity of spinal injuries has produced equivocal findings.
- Players at higher grades may be at relatively higher risk of injury because of the greater size and power of players, and the aggression with which the game is played.
- Mismatches in skill and experience are a major risk for injuries within the scrum.
- Unless rugby unions define what 'suitably trained and experienced' means within the context of front-row play for the various levels of the sport, a definition is likely to be decided upon in a court of law.
- Players occupying different positions face varying levels of risk of spinal injury. Hookers especially, and to a lesser extent props, are most frequently injured during scrums. Injuries occur both as a result of mistimed impacts (vertex and hyperflexion/rotation injuries) and scrum collapse (hyperflexion and rotation).
- Research into performance-related factors for rugby players suggests that rugby players of particular positions possess stereotypical physical attributes, which presumably confer an advantage in meeting the demands of the given position. Props and hookers have been demonstrated to be shorter, more endomorphic and less ectomorphic than other forwards are. Unless strong evidence emerges to the contrary, it is safer to err on the side of caution and continue to recommend that thin players, especially those with long thin necks, not be placed in the front-row positions.
- Backs sustain spinal injuries most often during tackles. Both the ball carrier and the tackler are at risk. The midfield backs (second five-eighths and centres) appear to be the backs that are injured most often. This may be caused by their role of 'crashing' into the opposition to set up second (or subsequent) phase ball for their team.
- Further work to examine the risks faced by rugby players with various congenital, developmental and post-injury conditions of the spinal column is warranted.
- The long-term impact of playing rugby on the health of the spines of participants should be examined, given that research has identified accelerated degenerative changes in the spines of players in the front-row positions. The extent to which acquired stenosis places players at risk of spinal injury should be examined with prospective studies.

5. Game-Related (Extrinsic) Risk Factors

5.1 Laws of the Game

The laws of the game set the structure within which the patterns of activity of rugby occur.[47] A report on developments in the scrum by the Injury Prevention sub-committee of the Rugby Foundation of New Zealand[62] suggests that law changes implemented in 1963 resulted in the desirability of slower ball emerging from the scrum, with resulting longer scrum times and greater pushing from flankers than had previously been the norm. This is thought to have lead to the development of power scrummaging through the 1970s, with the associated increased incidence of serious scrum injuries.[62] Over the past 20 years, there have been a number of law changes introduced to the game with the intention of decreasing the risk of serious injury. Law changes have been implemented both throughout the game, by the IRB, and via local 'experimental variations' within particular countries. These law changes have included alterations to the binding permitted in the scrum, changes to the replacement laws (as outlined in section 4.4.1) which mandate that a trained front-row player be available if a front-row player leaves the field, procedures for scrum engagement, and the ability of the touch judges to notify the referee of dangerous play. Changes to regulations and policies which impact on the way the laws of the game are applied can also alter patterns of player behaviour, without necessarily altering the 'letter of the law'. Thus, the degree to which changes in the law have impacted on spinal injuries within rugby is difficult to assess. Any law change is likely to result in changes to the typical structure and patterns of activity that are representative of the sport. Part of the reason for this is that after a law is modified, players and coaches generally attempt to use it to gain a competitive advantage over their opposition.

5.2 Phase of Play

The patterns in table III show that the phases of play associated with the greatest number of spinal injuries in rugby are the tackle and the scrum. Only about 6% of rugby-related spinal injuries were not associated with the tackle, the scrum, or the ruck and maul. As mentioned earlier, one of the primary limitations of this information is that we have no way of knowing how many scrums, tackles, and rucks and mauls were typical within rugby within each country studied over the various time periods, nor how many players were active within the region from which each study was taken.

Keeping these factors in mind, there do appear to be differences between countries in the proportion of injuries associated with phase of play. The fact that the relative frequency of occurrence by phase varies across the countries suggests that there may be avenues for injury prevention, which can be pursued by analysing the factors that contribute to these observed differences. Injury prevention initiatives that deal with the situation specific to the country could then be put in place.

A number of researchers have suggested that injury prevention messages directed at the scrum, which occurs in a relatively 'controlled' situation (compared with variability inherent in the tackle) could play a major role in decreasing the number of spinal injuries occurring in the sport. In New Zealand, seven scrum-related spinal injuries in the first 4 months of 1996 prompted compulsory safety courses for coaches. From 1976 to 1996, the proportion of spinal injuries in New Zealand from

Table III. Distribution of cervical spinal injuries in rugby by phase of play

Study	Country	Period of study	Tackle injuries		Scrum injuries		Ruck and maul injuries		Other/unknown		Total
			n	%	n	%	n	%	n	%	n
Secin et al.[29]	Argentina	1977-1997	5	27.8	11	61.1	2	11.1			18
Rotem et al.[63]	Australia	1984-1996	8	30.8	14	53.8	4	15.4			26
Taylor and Coolican[6]	Australia	1960-1985	8	21.6	23	62.2	5	13.5	1	2.7	37
Sovio et al.[8]	Canada (British Columbia)	1975-1982	2	22.2	7	77.8					9
Armour et al.[1]	New Zealand	1976-1995	39	32.8	53	44.5	17	14.3	10	8.4	119
Palairet and Xiong[37]	New Zealand	1996-2000	18	48.6	14	37.8	4	10.8	1	2.7	37
Kew et al.[4]	South Africa	1963-1989	59	50.4	25	21.4	21	17.9	12	10.3	117
Silver[42]	UK	1952-1982	23	36.5	14	22.2	20	31.7	6	9.5	63
Silver [64]	UK	1983-1987	5	26.3	7	36.8	6	31.6	1	5.3	19
Wetzler et al.[36]	US	1970-1984	18	30.5	34	57.6	7	11.9			59
Williams and McKibbin[35]	Wales	1966-1984	9	30.0	12	40.0	9	30			30
Total			**194**	**36.3**	**214**	**40.1**	**95**	**17.8**	**31**	**5.8**	**534**

scrums was 46.9% (combining data from Armour et al.,[1] and Palairet and Xiong[37]). In the 4 years subsequent to the courses (1997 to 2000), the proportion of scrum-related spinal injuries was 26.7%.[37] Unfortunately, the decrease in the number of scrum injuries has coincided with an increase in the number occurring in the tackle, leaving the number of spinal injuries occurring per year relatively constant through the period. This again highlights the point that until we better isolate the mechanisms responsible for injury and collect more reliable 'denominator' measures (including typical patterns of activity during matches), evaluating the effectiveness of any interventions will be difficult.

Research conducted in South Africa over the period 1985 to 1989 identified that the proportion of spinal injuries occurring in the tackle had increased, and that the fraction of injuries resulting in tetraplegia was higher in the tackle than in the scrum.[65]

5.3 Mechanisms of Injury

The majority of articles published in the sports/medical literature relating to spinal injuries have been case reports. While case reports are not able to provide strong evidence as to the *relative* risk of factors associated with spinal injuries (because the number and circumstances of the given risk factor(s) in which injuries were not sustained are not measured), they are useful in describing the mechanisms associated with those injuries that have occurred. Thus, detailed reports of the ways in which players sustained their injuries in various phases of the game have been presented. A useful summary and explanatory graphics of the most common mechanisms of spinal injuries in rugby has been presented by Noakes and du Plessis.[66]

5.3.1 Mechanisms of Scrum Injuries

Within rugby generally, and particularly within scrums, the most commonly reported injury mechanism is hyperflexion of the cervical spine, with or without rotation.[13] This mechanism is demonstrated in figure 3. The proportion of scrum injuries attributed to either scrum engagement or collapse varies greatly across studies (table IV).

As observed by Armour et al.,[1] a player who is paralysed upon scrum engagement will tend to collapse the scrum, so distinguishing the exact mechanism of injury within the scrum is not always straightforward. Injuries associated with scrum impact tend to occur when the front rows of the scrums crash together with some of the players unready. The players who are not ready may attempt to pull out of the engagement. The remaining players may drive directly into their opponents' torsos. The mechanism of injury in this situation has been described by Scher.[68]

5.3.2 Mechanisms of Tackle Injuries

Although case reports of mechanisms for tackle injuries in rugby have appeared, there does not appear to be a consensus among researchers about what the most common mechanism for injuries in the rugby tackle situation is. The tackle situation is more dynamic than the scrum, and it appears that players injured in the tackle often have less awareness of how the injury occurred than those injured in the scrum. Within New Zealand, the proportion of players spinally injured while tackling and while being tackled was approximately even,[1,37] a pattern that has been observed in other tackle injuries.[32] Types of tackles identified in case reports as being particularly dangerous in rugby include high tackles,[22,69,70] double tackles[20] and in rugby league 'spear tackles'.[71] Spear tackles in rugby and rugby league refer to tackles in which a player is lifted and then driven headfirst into the ground (as opposed to spear tackles in American Football, which refer to tackling with the vertex of the head as the first point of impact). In American Football, the mechanism of tackle injuries was clearly identified as being associated with vertex impacts that result in compression of the spinal cord.[72] Although it is uncommon for rugby players to attempt to impact their opposition with their head during a tackle, vertex impacts in rugby are presumably just as dangerous as those in American football. Although injuries caused by vertex impact resulting from rugby tackles have been reported,[73] it ap-

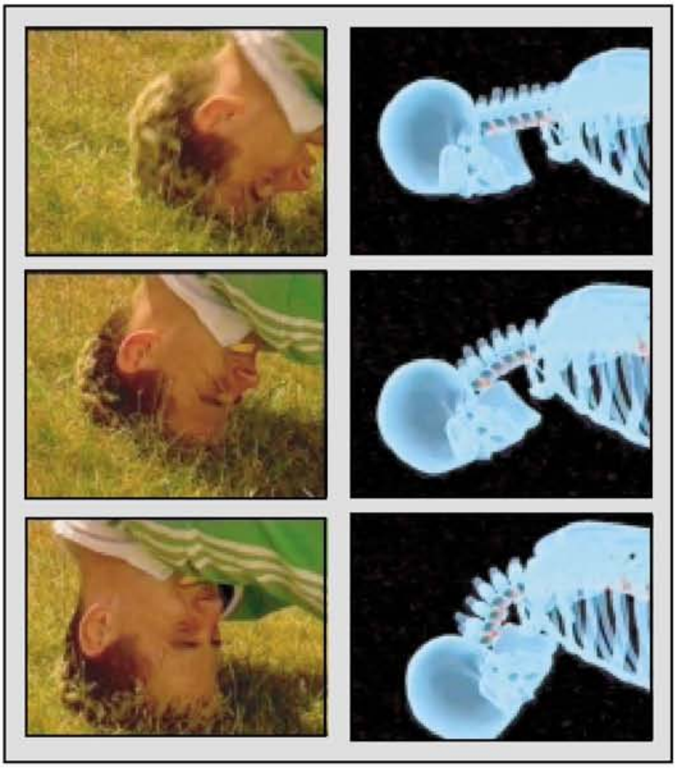

Fig. 3. Hyperflexion of the cervical spine resulting in fracture dislocation.

pears that the primary mechanism of injury within the rugby tackle is hyperflexion of the neck. Hyperflexion injuries in the tackle situation can occur to either the ball-carrier or tackler when they enter the contact situation with their neck flexed.[13]

Further videotape and epidemiological evidence is required to clarify the extent to which mechanisms in rugby tackles[13,66,68] differ from those in American Football tackles.

5.3.3 Mechanisms of Ruck and Maul Injuries

Scher[21] outlined three different ways in which spinal injuries were sustained during rucks and mauls. These were:

(i) forced flexion of the ball carrier's neck

(ii) forced flexion of the neck of the player at the bottom of the ruck

(iii) head and neck injury caused by charging into a mass of struggling players.

Although they make up approximately 17% of spinal injuries from the reported case series review papers, there has been little work that has sought to identify the risk factors associated with these phases of play.

5.4 Patterns of Injury by Month of Season

The proportion of all rugby injuries that occur early in the season is high.[74-76] The pattern of spinal injuries has been shown to follow a similar pattern in New Zealand,[1,37] South Africa[4] and the UK.[16] A number of researchers have suggested that the predominance of injuries early in the season emphasises the importance of physical conditioning prior to the beginning of the season.

Table IV. Mechanisms of scrum injuries

Reference	Country	Collapse		Scrum engagement		Popping		Other/unknown		Total
		n	%	n	%	n	%	n	%	n
Secin et al.[29]	Argentina	5	45.5	6	54.5		0.0		0.0	11
Taylor and Coolican[6]	Australia	7	30.4	15	65.2	1	4.3		0.0	23
Armour et al.[1]	New Zealand	26	49.1	23	43.4	4	7.5		0.0	53
Palairet and Xiong[37]	New Zealand	4	28.6	8	57.1	1	7.1	1	7.1	14
Silver[64]	UK	10	71.4	3	21.4		0.0	1	7.1	14
Silver and Gill[67]	UK	4	57.1	1	14.3		0.0	2	28.6	7
Wetzler et al.[44]	US	13	36.1	23	63.9		0.0		0.0	36
Williams and McKibbin[35]	Wales	9	75.0	1	8.3	2	16.7		0.0	12
Total		**78**	**45.9**	**80**	**47.1**	**8**	**4.7**	**4**	**2.4**	**170**

Figure 4 shows the pattern of injuries by time of season in New Zealand.[1] While the lower amount of rugby played from September to February (the off-season in New Zealand) is strongly reflected in the pattern above, the exposure to rugby (and rugby league) between April and August is relatively constant,[76] so it is not just a change in the amount of rugby faced by players.

Currently, there is a lack of research regarding what contributes to this pattern. Here are some potential contributors:

(i) Lack of experience in the skills required in the contact phases of the game. Trial games are likely to pit players with widely varying levels of experience and skill against each other – often players find themselves marking opponents who will end up playing in a different grade from themselves during the season. A mismatch in ability or experience has been identified in some research papers as being a potential risk factor for spinal injuries occurring in the scrum. In the US, researchers who completed a 20-year survey of rugby-related spinal injuries concluded that '9 of the 36 cervical spine injuries (25%) that involved front-row players were documented cases of mismatches of experience'.[44] Factors that increase the likelihood of this occurring include:

- Players are probably more likely to take up a new position at the start of the season.
- New players generally enter the sport at the start of the season.

(ii) Lack of continued practice at the skills involved in the contact phases of the game.

- Players do not usually practice tackling, scrummaging, rucking or mauling in the weeks leading up to the season. This may lead to them being more likely to be placed in physical positions that can result in injury. Upton et al.[77] found that in some South African schools less than 30 minutes was allocated to the practice of tackling and falling techniques prior to the first full-contact match.

(iii) Lack of impact conditioning – players often perform aerobic, anaerobic, speed, strength and power training over the off-season. Conditioning the body to cope with the impacts that are a major part of rugby is ignored by the majority of players (although this is beginning to change). Players, even those who have trained to increase their aerobic fitness and strength are generally at their 'softest' at the beginning of the season.

(iv) The first matches of the season are often trials, where players are likely to play as hard as possible in the attempt to make the team they aspire to. So there is no 'progressive overload' in terms of impact.

(v) Harder grounds at the beginning of the season – which leads to increased impact forces when players hit the ground after tackles and during rucks, mauls and collapsed scrums.[25]

(vi) Combined lack of familiarity in the front row – players who are not used to each other may be unsure of their combined course of action in the event of a collapsed scrum.[35]

5.5 Spinal Injuries Occurring as a Result of Illegal or Foul Play

A number of studies have noted that foul or illegal play contributes to avoidable spinal injuries. In South Africa,[4] only 3% of reported spinal injuries were a result of foul play compared with 11% in the UK,[42] and 26% across all football codes in Australia.[6] In New Zealand, surveys of club players suggest that the proportion of all injuries attributed to foul play has dropped from 13% in 1993 to 7% in 1997 to 1998.[78]

Injuries that result in permanent loss of function because of foul play are unacceptable. Despite rugby players assuming the risks inherent in a physical contact sport, a deliberate act that caused another to be seriously injured could result in criminal or civil proceedings being brought against the player who caused the injury.

5.6 Immediate Management of Rugby Spinal Injuries

Incorrect management of spinal injuries has the potential to result in spinally injured players who would otherwise fully recover, becoming permanently paralysed. This is especially relevant given that research in Ireland[79] and South Africa[80] has identified that in many cases coaches are the only individuals available to provide first-aid to injured players and that a substantial portion of these had received no training in first-aid. It is essential that coaches at all levels of contact rugby are educated with regard to the correct steps to take in the event of spinal injuries. A comprehensive overview of prehospital care of spinally injured athletes has been provided by the National Athletic Trainers Association.[81] At the higher levels of the sport, the responsibility for injury management is more likely to be given to somebody who has some medical training. It is still essential for this individual to be trained in first-aid, as general medical training (and in some cases even sports medicine training) does not necessarily provide specific guidance on immediate management of spinal injuries.[82] Environmental concerns, such as having appropriate first-aid equipment on hand and ambulance access, should also be given high priority in education programmes for club and school rugby administrators.

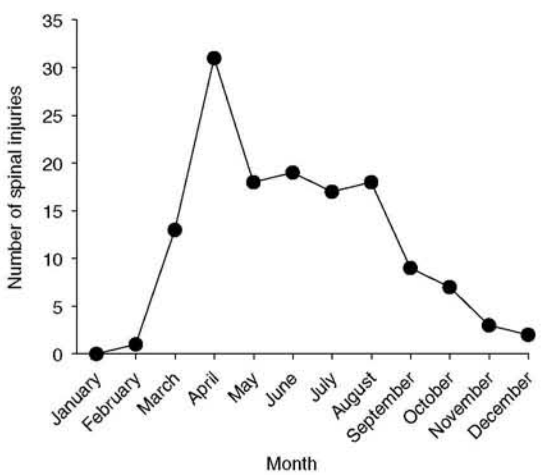

Fig. 4. Spinal injuries in New Zealand by month (1976 to 1995) [from Armour et al.,[1] with permission].

5.7 Summary of Extrinsic Risk Factors for Spinal Injury

- The laws of the game set the structure within which patterns of play are permitted. A number of law changes have been implemented in attempts to lower the incidence of spinal injuries. The degree to which these have impacted on spinal injury rates has been difficult to assess for a number of reasons including lack of measurement of player numbers, variations in classifications of injury across and within countries, and the typical variations that are expected over time in rare, independent events.
- Within the constraints of the information available, it appears that there are differences across countries in the phase of play in which spinal injuries are most commonly occurring. In some countries, the proportion of injuries occurring in the scrum appears to have dropped, and the

proportion occurring in the tackle appears to have increased through the 1990s.

- The incidence of injuries appears to be higher in the early part of the season. This pattern has been noted in a number of countries, and may be related in part to a lack of adequate physical preparation and practice at the contact phases of the game.
- Injuries resulting in permanent disablement as a result of foul or illegal play have been reported in the literature. These are unacceptable, and are likely to result in civil or criminal proceedings against the perpetrator of the act.
- Incorrect management of spinal injuries immediately after they occur has the potential to worsen the prognosis dramatically. It is essential that those responsible for first-aid are trained in how to provide correct immediate management of spinal injuries.

6. Examination of Changes in Frequency and Severity of Spinal Injury Over Time

While it appears that the frequency of spinal cord injuries to rugby players has increased over the past 30 years, it is difficult to know what proportion of the increase is attributable to:

- greater awareness of the problem due to increased publicity
- better record keeping and greater depth of study
- changes in playing populations
- changes in exposure per player per season
- changes in patterns of activity in matches, including an increase in competitiveness of play
- changes in the anthropometric and physiological characteristics typical of players
- increased rate of admission of players to spinal units to ensure optimal treatment.

Part of the difficulty in comparing injury rates between countries (or studies) is the difficulty in classifying spinal injuries. Because the diagnosis can change substantially from the initial appraisal to the time a player leaves a spinal unit, it is difficult to standardise measures of injury severity. In addition, as Taylor and Coolican[6] pointed out, while the American Spinal Injury Association (ASIA) classification (outlined in section 6.1) gives broadly useful groupings of motor and sensory function, a large degree of variation exists within category 'D', which can range from relatively mild to quite severe impairment (the same applies to the Frankel classification system,[83] which is similar to the ASIA system).

6.1 The American Spinal Injury Association Classification System of Spinal Injuries

The ASIA classification system of spinal injuries[84] provides groupings of motor and sensory function under the following categories:

A = Complete loss of sensation and movement below the level of the injury (wheelchair bound)
B = Incomplete loss of sensation, loss of movement (wheelchair bound)
C = Incomplete loss of movement in lower limbs (wheelchair bound)
D = Incomplete cord injury – severe injury/perhaps able to walk/perhaps wheelchair bound
E = No permanent damage.

A South African review[85] suggested that the number of rugby-related spinal injuries admitted to the Spinal Cord Injury Centre at Conradie Hospital in Cape Town had risen from 5.4 per year for the period 1981 to 1987, to 8.7 per year from 1987 to 1996. A similar increase has been observed in New Zealand. The number of spinal injuries admitted to the Burwood Spinal Unit in Christchurch, New Zealand resulting from rugby during the period 1979 to 1988[57] was 28. Fifteen of these players were complete tetraplegics (Frankel A classification) and two were incomplete tetraplegics (Frankel B). The proportions falling into each Frankel classification are shown in figure 5.

For the subsequent 10-year period, (1989 to 1998) a large increase in the number of spinal injuries was reported (53 injuries; T Hughes, unpublished data). The average severity, however, was lower (figure 6).

Over the second 10-year period, nine injuries resulted in complete tetraplegia. Several researchers have drawn attention to the number of serious neck injuries sustained in rugby that do not result in damage to the spinal cord.[48,85] It has been suggested that for every serious spinal cord injury sustained by rugby players, there may be as many as ten 'near miss' injuries to the neck that do not result in spinal cord involvement.[4] Two particular observations that resulted from studying these injuries were the occurrence of spinal cord concussion injuries, in which players experienced transient paralysis, and the large number of players who had degenerative changes of the cervical spine (as described in section 4.5.2).[85] A question of interest regarding the so-called 'near miss' injuries is whether risk factors for spinal injury in rugby vary across the spectrum of severity of injury. If the factors that predispose players to the more severe injuries differ from those that predispose players to the less severe injuries identification of risk factors via prospective methods will be more difficult. Sufficient data to examine the differences will take longer to collect than if similar risk factors predisposed to injuries across the spectrum of severity.

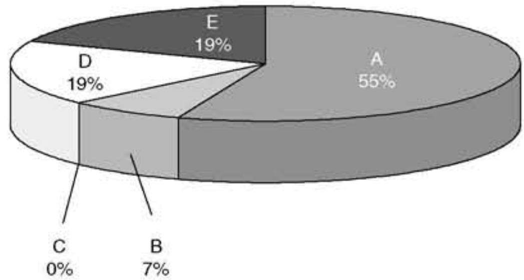

Fig. 5. Frankel classification of rugby-related spinal injuries in New Zealand (1979 to 1988) [Hughes T, personal communication]. **A** = complete loss of function; **B** = motor complete, sensory incomplete; **C** = motor nonfunctional; **D** = motor functional; **E** = complete recovery.

7. Comparison of Injury Rates Across Studies/Countries

Until standard definitions of injury are used and accurate estimates of player populations are available, comparing incidence rates across rugby playing nations is not particularly useful.

The best estimates currently available for Australia suggest a rate of injuries resulting in tetraplegia or quadriparesis of 6.5/100 000 participants per year during the period from 1984 to 1996.[63] For the purposes of comparison, if the number of players in New Zealand through the same period had been approximately 120 000 (as it is currently estimated to be), the rate would have been 2.3/100 000 participants per year. A recent report from Fiji indicated that the incidence of rugby-related spinal injuries in that country resulting in death or tetraplegia may be as high as 10/100 000 players per year,[45] although the sample size is small and may reflect seasonal variation.

7.1 Comparison of Spinal Injury Rates in Rugby Union with Rugby League and American Football

Rugby League (league) is the football code that is most similar to Rugby Union in terms of the patterns of play that are typical within the sports, although there are a number of key differences. Among these are:

- There are 15 players on a rugby team versus 13 on a league team (there are eight forwards on each team in rugby, whereas there are six on each team in league).
- The scrum is contested much more aggressively in rugby than is the case in league.
- If the ball travels out of play over the sideline, possession is contested in rugby in a lineout, whereas in league possession of the ball automatically goes to the team who were not responsible for taking the ball out of play.
- The games also differ in terms of what occurs after a tackle. In league, the tackled player is allowed to stand up and provide the ball to their team by heeling it backwards with the foot. In rugby, a ruck or maul consisting of variable numbers of players forms over the tackled player, and possession of the ball continues to be contested.

Compared with rugby, a greater proportion of spinal injuries in league tend to occur in the tackle,

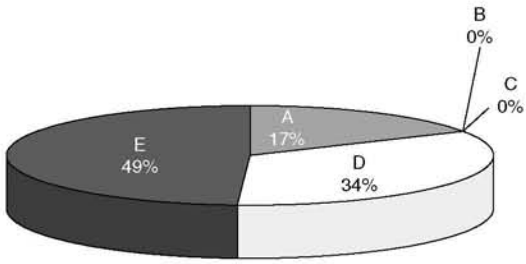

Fig. 6. Frankel classification of rugby-related spinal injuries in New Zealand (1989 to 1998) [Hughes T, personal communication]. **A** = complete loss of function; **B** = motor complete, sensory incomplete; **C** = motor nonfunctional; **D** = motor functional; **E** = complete recovery.

and a lesser proportion occur in the scrum. In New South Wales, Australia, Rotem and colleagues[63] reported that during the period 1984 to 1996, 78% of spinal injuries in league occurred in the tackle, with the remaining injuries (22%) occurring in the scrum. In rugby during the same period, 54% of spinal injuries occurred in scrums, 15% in rucks and mauls, and 31% in the tackle. There were 23 injuries that resulted in neurological deficits in league, which represented a rate of 1.7 injuries/100 000 players per year. In Rugby Union, there were 26 injuries that resulted in neurological deficits, which represented a rate of 6.5 injuries/100 000 players per year. These authors concluded that there appeared to be several options based on their findings:[63]

- Maintain the status quo and accept that each year several union and league players in New South Wales (and elsewhere) will sustain cervical spinal cord injuries that will leave them permanently paralysed below the neck.
- For rugby union, change the rules (laws) to substantially reduce the number of scrum-like plays and change the organisation of the scrum.
- For rugby league, introduce changes to the rules aimed at substantially altering the nature of the tackle.

Although the games are quite different, is interesting to attempt to compare the rate of spinal injuries within rugby and American Football. An annual rate of tetraplegia of 0.5/100 000 players in high school football and 1.2/100 000 players for college football has been reported in the US.[86] From 1995 to 2000, the combined rate of injuries with incomplete neurological recovery for American Footballers at College and High School level has been 2/100 000 players per year.[87] Over the same period in New Zealand (assuming the number of players has been relatively constant at 120 000), the rate has been 2.8/100 000 players per year.[37]

8. Recommendations

The analysis of information obtained through the implementation of a national register of spinal injuries for American Football allowed identification of the main mechanisms of injury in that sport. As a result of changes that were implemented, a substantial drop in injury rate was observed.

Joseph Torg,[72] who was one of those responsible for setting up a case register of injuries in American Football, summarised the way in which other sports could take advantage of the lessons learned in the American situation as follows:

- continued research
- development of clear and concise definitions of the responsible injury mechanisms based on sound biomechanical, epidemiologic, and clinical evidence
- education of coaches and players
- enforcement of rules is essential.

The risk of not following a systematic approach to data collection and analysis of these injuries is that any developments within rugby (whether through law changes or changes in play as a result of new tactics) cannot be evaluated in terms of safety.

In order to make real changes to the incidence rate of serious spinal injuries throughout the rugby-playing nations of the world, the following recommendations are set forth:

(i) Institute a systematic international case register that has the potential to be replicated throughout the IRB member countries.

(ii) Ensure that each team has assigned to it an appropriately trained person responsible for first-aid and that processes are in place for minimising harm to players who sustain an injury. This is important at all levels of the sport that involve contact scrums and tackles.

(iii) Ensure that each team has a clearly designated 'injury official', who is responsible for notifying serious spinal injuries to the national administrators of rugby.

(iv) Coaches should attempt to minimise the 'mismatching' of players of different levels of skill during trials.

(v) Educate coaches and players about the importance of progressively preparing their bodies for the impacts that are part of the game. Moving directly from 'no impact' to 'full on games' may mean that players are less able to cope with any impacts that do occur during tackles, scrums, rucks and mauls.

(vi) Players should practice the skills involved in tackling and scrummaging again at the start of each season prior to starting the playing season proper. This could easily be incorporated into pre-season fitness training that is commonly held at clubs. This would also assist those players who lack experience in impact to gain this experience in a more controlled environment than in a game.

(vii) Consider building up to full impact in scrums over the series of trial matches (possibly starting with static scrums in the first trial match or two of the season).

(viii) Continue to ensure that the laws regarding dangerous play are strictly enforced.

(ix) Consider starting the club season slightly later in the year to allow play on softer grounds.

9. Conclusion

An increase in the frequency of rugby related spinal injuries was reported through the latter part of the 1970s and the early 1980s in most countries where rugby is commonly played. While the scrum was the phase of play most commonly associated with spinal injuries throughout the 1980s, there has been a trend through the 1990s of an increasing proportion of spinal injuries occurring in the tackle situation. Within the constraints of the research published to date, it appears that hookers and props have been at disproportionate risk of cervical spine injury, predominantly because of injuries sustained during scrummaging. The majority of injuries from all phases of play have occurred early in the season, when grounds tend to be harder and players are lacking both practice and physical conditioning for the physical-contact phases of the sport. Research into the long-term effects of participation in rugby on the integrity of the spinal column is warranted. Case reports and case-series studies have provided much information regarding the mechanisms and frequency of rugby injuries to the cervical spine and spinal cord. The most commonly reported mechanism of injury has been hyperflexion of the cervical spine, resulting in fracture dislocation of C4-C5 or C5-C6. This differs from the most common mechanism in American Football, in which spinal cord damage results through impact to the vertex of the head. Further investigations should be undertaken to quantify the extent of this difference. A number of injury-prevention measures have been launched, including changes to the laws of the game regarding scrummaging, and education programmes aimed at enforcing safe techniques and eliminating illegal play. Tracking both the trends of incidence of spinal injuries, and the effectiveness of injury prevention initiatives, has proved difficult because of a lack of properly conducted epidemiological studies. Calls for case-registers and effective epidemiological studies have been made by researchers and physicians in most countries where rugby is widespread, but it appears to be only recently that definite steps have been made towards this goal. Well-designed epidemiological studies that entail international collaboration will be able to provide more accurate information about potential risk factors for injury such as age, grade, position, gender and ethnicity than has been the case in the past. These studies will require cooperation among rugby administrators at a variety of levels of the sport, epidemiologists, and orthopaedic and spinal surgeons.

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THESIS CHAPTER 2

EFFECT OF NATIONWIDE INJURY PREVENTION PROGRAMME ON SERIOUS SPINAL INJURIES IN NEW ZEALAND RUGBY UNION: ECOLOGICAL STUDY

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RESEARCH

Effect of nationwide injury prevention programme on serious spinal injuries in New Zealand rugby union: ecological study

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ABSTRACT

Objective To investigate the effect of RugbySmart, a nationwide educational injury prevention programme, on the frequency of spinal cord injuries.

Design Ecological study.

Setting New Zealand rugby union.

Participants Population at risk of injury comprised all New Zealand rugby union players.

Intervention From 2001, all New Zealand rugby coaches and referees have been required to complete RugbySmart, which focuses on educating rugby participants about physical conditioning, injury management, and safe techniques in the contact phases of rugby.

Main outcome measures Numbers of all spinal injuries due to participation in rugby union resulting in permanent disablement in 1976-2005, grouped into five year periods; observed compared with predicted number of spinal injuries in 2001-5.

Results Eight spinal injuries occurred in 2001-5, whereas the predicted number was 18.9 (relative rate=0.46, 95% confidence interval 0.19 to 1.14). Only one spinal injury resulted from scrums over the period; the predicted number was 9.0 (relative rate=0.11, 0.02 to 0.74). Corresponding observed and predicted rates for spinal injuries resulting from other phases of play (tackle, ruck, and maul) were 7 and 9.0 (relative rate=0.83, 0.29 to 2.36).

Conclusions The introduction of the RugbySmart programme coincided with a reduction in the rate of disabling spinal injuries arising from scrums in rugby union. This study exemplifies the benefit of educational initiatives in injury prevention and the need for comprehensive injury surveillance systems for evaluating injury prevention initiatives in sport.

INTRODUCTION

Rugby union is a type of full contact football most commonly played between two teams of 15 players. The sport has an international following—the International Rugby Board, which is the sport's governing body, lists 95 countries in its online world rankings, although rugby is a major sport in fewer than 20. Box 1 gives a glossary of rugby related terms.

Spinal cord injuries, although rare on the basis of exposure per player, are a major cause of serious morbidity and mortality in rugby.[1] During the 1970s and 1980s an increase in the reported frequency of catastrophic spinal injuries associated with rugby was documented in medical journals from several countries in which rugby is a popular sport. The attention generated by letters to journals,[2 3] case reports,[4-6] and case series studies[7-10] prompted rugby administrators to act during the 1980s and 1990s to decrease the risks of spinal cord injuries, especially those related to the scrum. Measures to prevent injury have included changes to laws on scrum procedures, stricter application of existing laws, and educational initiatives.[11 12] Further case series studies have appeared recently.[11 13-19] Legal actions by injured players against referees, other players, and administrators have also contributed to raising the awareness of the importance of minimising the risks of rugby players sustaining permanently disabling injuries.[20 21]

A review of papers published up to 2001 reported that 40% of spinal injuries occurring in rugby were the result of the scrum, 36% were from the tackle, 18% from the ruck/maul, and the remainder were from either other or unknown causes. The definition of injury used in the studies reviewed, however, varied from admissions to spinal units (of which a proportion of players made full recoveries) through to tetraplegia.[1]

Ascertaining the numbers of spinal injuries occurring in rugby and the risks faced by players both in the scrum and in other facets of the game has been hampered by the relative rarity of the events and a lack of standardised procedures for collecting data.[1-12 22] In some countries, registers of spinal cord injuries exist on a national basis; in others, only regional data are available. A further impediment to evaluating the risks of spinal injuries in rugby has been a lack of reliable "denominator" data—the number and exposure of participants from which the cases result over a specified period.[22]

A recent call by a consultant general surgeon in the United Kingdom to ban the rugby scrum, which was based on his personal experiences as a rugby medical officer,[23] generated a flurry of correspondence in the electronic pages of the *BMJ*. The article cited evidence from an Australian survey that reported the elimination of scrum related spinal cord injuries in rugby league after the adoption of non-contested scrums in 1996.[14] Correspondents expressed widely divergent opinions as to the merits or otherwise of such an action being taken in rugby union.

Our study had two aims. The first was to document the number of permanently disabling spinal injuries in New Zealand rugby union from 1976 to 2005. The second was to investigate whether the incidence of spinal injuries in New Zealand rugby union changed after the introduction in 2001 of RugbySmart, a nationwide injury prevention programme.

METHODS

Number of spinal injuries

To examine trends in the incidence of rugby related spinal injury in New Zealand, we collated and analysed data from 1976 to 2005 on the frequency and circumstances of rugby related spinal injuries. We extracted incidence data from the Accident Compensation Corporation database for serious rugby related spinal injury claims. The Accident Compensation Corporation is a no fault insurance system funded from taxes, which provides personal injury cover for all New Zealand citizens, residents, and temporary visitors. In return, people do not have the right to sue for personal injury, other than for exemplary damages. People make a claim at the time of seeking treatment. Across the population of New Zealand (4 million) approximately 1.6 million claims are made annually from all causes. Any serious injury that requires medical assistance automatically generates an Accident Compensation Corporation claim. The Accident Compensation Corporation uses the American Spinal Injury Association scales A to D to classify serious spinal injury claims that involve permanent functional impairment resulting from damage to the spinal cord.[24]

In addition to Accident Compensation Corporation data, we cross checked files from the New Zealand Rugby Foundation (using name, date of birth, and date of injury) to provide additional information about the phase of play in which the injury occurred. The New Zealand Rugby Foundation is part funded by the New Zealand Rugby Union and provides assistance beyond that delivered by the Accident Compensation Corporation to permanently disabled rugby players in New Zealand. For the purposes of modelling injury rates, we categorised the phase of play as scrum and other (tackle, ruck, and maul).

Box 1 | Glossary of rugby terms

Rugby union—A type of full contact football, usually played between two teams of 15 players. Players may carry the ball and pass or kick it. Points are scored by placing the ball over the opposition goal line or by kicking goals. Ten and seven a side versions of the sport are also played. The rules of the game are termed laws and are available at www.irb.com/EN/Laws+and+Regulations/

Rugby league—A variant of rugby played between two teams of 13 players and governed by a separate administrative body from rugby union. Rugby union and rugby league developed from the same parent game; although they have many similarities, some important differences exist. After a tackle in rugby league, the tackled player is allowed to stand up and restart play by placing the ball on the ground and hooking it back to a team member standing behind him. There are no rucks or mauls of the type that occur in rugby union. Scrums in rugby league involve minimal pushing, whereas pushing is a major feature of rugby union scrums

International Rugby Board—The governing body of the sport of rugby union internationally

New Zealand Rugby Union—The governing body of the sport of rugby union in New Zealand

New Zealand Rugby Foundation—A charitable body that provides financial and other assistance to permanently disabled rugby players in New Zealand

Forwards—Player numbers 1 to 8. The main role of forwards in rugby union is to win and retain possession of the ball

Backs—Player numbers 9 to 15. The main role of the backs in rugby union is to attempt to gain field position and score points

Scrum—A means of restarting play after minor infringements. The forwards from each team form together in three rows and close up with their opponents so that the heads of the front row players interlock. This creates a tunnel into which the ball is thrown. The front row players contest possession of the ball by hooking the ball back with their feet

Tackle—When a ball carrier is held by one or more opponents and is brought to the ground. Following a tackle in rugby union, play continues

Ruck—In rugby union, a ruck is a phase of play (often after a tackle) that occurs when the ball is on the ground. One or more players from each team, who are on their feet and are in physical contact, close around the ball and contest possession

Maul—Similar to a ruck except that the ball is off the ground and is held by a player who is simultaneously held by one or more opponents and a team mate

Bledisloe Cup—A rugby union trophy contested between the international teams of Australia and New Zealand

Spinal injury rates

We used records of numbers of players, available from the New Zealand Rugby Union from 1998 onwards, to estimate the average incidence of spinal injury per 100 000 players per year for the periods 1996-2000 and 2001-5 (table). We estimated the player numbers in 1998-2000 by using a combination of player registrations and evaluation of competition draws. From 2001, the New Zealand Rugby Union put in place a new registration system and the player numbers represent registered players only. To calculate the rate in 1996-2000, we used the average number of players from 1998-2000 as the denominator for the entire period, assuming that the numbers in 1996 and 1997 did not differ substantially from those in the following three years.

RugbySmart programme

Since January 2001, RugbySmart (www.rugbysmart.co.nz) has been the vehicle for delivering information on injury prevention to rugby coaches, referees, and players in New Zealand. The RugbySmart programme derives its approach from van Mechelen's sequence of prevention model.[25] The four steps of the model involve establishing the size of the injury problem (generally through surveillance), identifying the risk factors and causes of the injuries sustained in the activity, implementing preventive measures, and continuing injury surveillance or monitoring programmes.[25] Such ongoing injury surveillance programmes are designed to investigate whether the changes implemented have had a beneficial role in reducing the injury burden.

Establishing the size of the injury problem and identifying risk factors/causes

In New Zealand, information on the size of the injury problem in rugby has been derived primarily from the number and costs of claims to the Accident

Compensation Corporation. Risk factors for and causes of rugby injuries have been derived from both case reports[4-6] (primarily describing injury mechanisms) and prospective cohort studies designed for this purpose, both in New Zealand[26-28] and from other countries.[29 30]

Implementing preventive measures

The RugbySmart programme builds on work to prevent rugby injuries that has taken place in New Zealand since the early 1990s. A summary of the strategies used has been presented elsewhere.[31] RugbySmart represented an increase in the level of partnership between the Accident Compensation Corporation and the New Zealand Rugby Union and a substantial increase in financial resourcing of injury prevention in rugby. A full time position (manager of research and injury prevention) was created within the New Zealand Rugby Union to act as a driver for the development and delivery of RugbySmart.

RugbySmart is a multifaceted injury prevention programme and has developed over time as new information about risks has emerged. Research into the epidemiology of sports injury generally, and rugby injury especially, is monitored and evaluated in terms of relevance for inclusion in the updated RugbySmart materials in an attempt to provide evidence based best practice information on injury prevention to rugby participants.

Both players and coaches in New Zealand have identified rugby coaches as having a key role in communicating information on injury prevention and attitudes to players' safety.[31] In recognition of this, the board of directors of the New Zealand Rugby Union mandated that all coaches must complete RugbySmart on an annual basis. Coaches who did not comply with this directive were threatened with having their team withdrawn from competition. Players also saw referees as having an important role in maintaining safety.[31] Referees who did not complete RugbySmart were not assigned matches. Trained personnel deliver the programme at a local level. Most of the people who deliver the seminars are rugby development officers and referee education officers employed by provincial unions or clubs. More than 8000 coaches and 1500 referees have attended RugbySmart annually since it was introduced. Because completing RugbySmart is compulsory, the reach of the programme to coaches and referees is close to 100%.

Information and resources have been made available through compulsory seminars, the production of DVDs, a dedicated website, and provision of injury prevention "tools," such as a sideline concussion check card, to coaches and referees. Opinion pieces on various aspects of injury prevention have been a regular feature of the New Zealand Rugby Union coaching magazine (distributed free of charge to all New Zealand coaches three times a year). The principles espoused in RugbySmart with respect to safety in contact have been integrated throughout New Zealand Rugby Union coaching courses. Key messages on injury prevention, such as the relation between injury prevention and performance, techniques to minimise injury risk in the contact situations of rugby (box 2), the importance of progressive physical conditioning (especially with respect to building up to contact during the preseason period), and management of acute injuries, have been heavily marketed so that they will be acceptable to participants. This has been done in part by using high profile coaches, medical staff, and physical conditioning experts to feature in the DVDs. These people have widespread credibility with the audience to which the programme is primarily directed.

Monitoring and surveillance

Ongoing research into risks and monitoring of the incidence of rugby injury has occurred at various levels over the period of the programme. Beyond the nationwide injury data captured by the Accident Compensation Corporation, the Injury Prevention Research Unit from the University of Otago had injury surveillance projects in 2003-5 to examine self reported injury rates and injury prevention behaviours and attitudes among nationwide samples of players. A video based system for capturing injury data has been used to identify risks and circumstances of match injuries in professional rugby competitions in which New Zealand teams competed in 2002-5.

Player numbers and injury rate per year

Year	No of players (thousands)	Change from previous year (%)	Scrum injuries	Other injuries	Injury rate (per 100 000 players per year)
1996	NA	NA	3	1	NA
1997	NA	NA	0	1	NA
1998	122	NA	0	2	1.6
1999	130	6	4	1	3.9
2000	129	−1	2	3	3.9
2001	120	−7	0	2	1.7
2002	122	1	0	1	0.8
2003	121	−1	0	2	1.7
2004	129	6	1	1	1.6
2005	138	6	0	1	0.7

NA=not available.

Statistical analysis

To examine the effect of the RugbySmart programme, we used the generalised linear modelling procedure (Proc Genmod) in SAS version 9.1 to calculate changes in numbers of scrum related and other spinal injuries before and after the introduction of RugbySmart. The aim of the modelling was to estimate the linear effect of time period on the number of injuries per five year period. The model was of the form injury number= RugbySmart period, where RugbySmart was coded as 1 for the period 2001-5 and 0 otherwise, and period was the five year period presented in the figure. We did not build participation level (number of players) into the model, because accurate estimates of numbers of players were not available before 1998. The model implicitly assumes constant player numbers over the entire period.

Owing to the nature of the dependent variable (count of injuries per five year period), we chose the Poisson response probability distribution. We made magnitude based inferences about true (population) values of effects by expressing the uncertainty in the effects as 95% confidence intervals.[32] We deemed an effect to be unclear if its confidence interval overlapped the thresholds for substantiveness (that is, if the likelihood of the injury rate ratio being substantially greater than 1.2 and less than 0.83 were both 2.5%).[33] To estimate the minimum clinically important difference, we calculated the typical number of spinal injuries occurring from scrums per five year period. A factor decrease of 1.2 equated to one person not being permanently disabled through a scrum related spinal injury per five year period, which we believed was a worthwhile clinical outcome. We aggregated counts into five year periods to avoid problems of zero cell counts[34] and to give a single prediction for the last five years for comparison with the observed incidence.

RESULTS

Seventy seven permanently disabling injuries were recorded in 1976-2005. In 1976-2000 the scrum accounted for 48% (33/69) of spinal injuries; in 2001-5 the percentage was 12.5 (1/8). Tackles accounted for 36% (25/69) of spinal injuries in 1976-2000 and 87.5% (7/8) in 2001-5. The remaining 11 injuries resulted from the ruck or maul. The figure shows the frequency of permanently disabling spinal cord injuries in New Zealand rugby grouped by five year period from 1976.

In 2001-5 eight spinal injuries occurred in New Zealand rugby, whereas the predicted number based on the rate from the previous periods was 18.9 (relative rate=0.46, 95% confidence interval 0.19 to 1.14). Only one scrum related spinal injury occurred in 2001-5, which was clearly less than the predicted number of 9.0 (relative rate=0.11, 0.02 to 0.74). Seven spinal injuries occurred as a result of tackles, rucks, and mauls in 2001-5; the predicted number was 9.0. The difference in the number of observed spinal injuries resulting from tackles, rucks, and mauls relative to the predicted number was rated unclear (relative rate=0.83, 0.29 to 2.36).

The average annual number of players registered was 126 800 in 1996-2000 and 125 900 in 2001-5. The rates of spinal injuries from scrums and from other phases of play per 100 000 players per year were therefore 1.4 and 1.3 in 1996-2000 and 0.2 and 1.1 in 2001-5.

DISCUSSION

RugbySmart and spinal injury numbers

A major goal of the New Zealand Rugby Union and the Accident Compensation Corporation in establishing RugbySmart was "to eliminate spinal injuries within the context of a contact sport." The results are consistent with a decrease in spinal cord injuries in New Zealand rugby since 2000, primarily owing to a reduction in injuries occurring in scrums. This decrease coincides with the introduction of the RugbySmart programme. The ability of the governing body of New Zealand rugby to require completion of RugbySmart as a prerequisite to being able to coach or referee has led to the programme having extensive reach among people identified as important for communicating messages on injury prevention to improve players' safety.

If the true rate of scrum related spinal injury was the observed average rate of 6-7 per five years, the chance of observing one or zero scrum related spinal injuries in 2001-5 if the underlying rate of injury to players had not changed and the total exposure of players to rugby had remained constant was only 1%. Thus a small chance exists that the decrease observed in this study reflects expected statistical variation, but a real decrease in the rate of spinal injuries from scrums occurred in New Zealand over the period 2001-5 is much more probable.

Although the number of sports injury prevention programmes running worldwide has greatly increased over the past two decades, few have completed all four steps inherent in the "sequence of prevention" model.[25 35] RugbySmart is one of the first examples of a nationwide programme to have evaluated the effects of the injury prevention initiatives introduced through ongoing nationwide surveillance. The RugbySmart programme was designed to be an injury prevention system that provides participants with up to date information about risks of rugby injury and preventive techniques. Evaluation of the programme, which will be discussed in depth in a paper in preparation, consists of targeted injury surveillance projects; examination of participants' knowledge, attitudes, and behaviours; and monitoring of Accident Compensation Corporation claims.

One of the weaknesses of this study is the lack of a control group. Because the New Zealand Rugby Union wanted to implement a nationwide injury prevention programme from the beginning, we were unable to create a control group to which RugbySmart was not delivered. Although the finding that numbers of spinal injuries in New Zealand rugby have decreased is positive regardless of the reasons for the drop, examining factors besides the RugbySmart programme that may have contributed to the decline can help us to assess how much weight we should place on the apparent impact of RugbySmart.

Box 2 | **Common principles for safe technique in contact in rugby union promoted in RugbySmart**

- Eyes focused on target area
- Chin up, eyes open
- Low body position
- Keep back flat
- Shoulders above hips
- Use legs to drive powerfully into contact

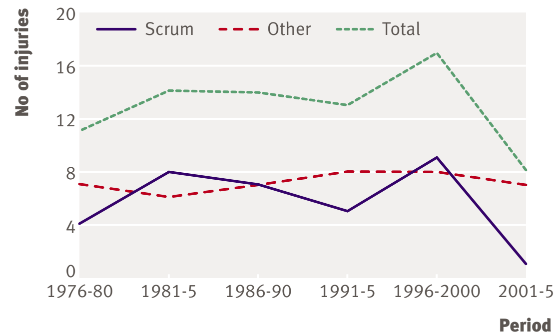
Changes in law are a means of altering behaviour that have the potential to decrease the risk of injury. In 1992, the International Rugby Board introduced a change that altered the sequence of events in scrum engagement. Little evidence suggests that any decrease in scrum related spinal injuries in New Zealand that followed this change was sustained through the subsequent five year period (see figure). No substantive changes occurred to the law relating to the scrum, ruck, maul, or tackle through the period of the RugbySmart intervention (2001-5) that would have been expected to affect players' risk of sustaining a spinal injury.

Players' exposure to scrums, tackles, and rucks

A decrease in exposure to scrums could have contributed to the decrease in the number of scrum related spinal injuries seen in 2001-5 compared with previous periods. Such a decrease in exposure to scrums could have resulted from fewer players participating in rugby, fewer matches a year for those who did participate, fewer scrums per match, or some combination of the three. The amount of confidence we can have in discounting these varies. For example, although an overall decrease in scrum related spinal injuries between 1996-2000 and 2001-5 similar to that seen could have resulted with no change in risk per player had the number of players decreased enough, the actual number of players needed before the intervention to allow a large enough decrease is unfeasibly high. This would have required a playing population in 1996 and 1997 of 2.6 million, or around 20 times higher than the number of players recorded in the following years. Over the longer term, we have little evidence on which to base any conjecture of the possible impact of numbers of players on numbers of injury.

Decreases in the typical exposure per player (assuming that the number of players remained constant), commensurate with fewer matches being played in a season, could also result in a lower number of spinal injuries being seen. Across all levels, the number of competitions and the number of matches played per competition have not, to our knowledge, changed substantially in New Zealand over the past decade. The New Zealand Rugby Union has no information to suggest that this has been the case, although the relative balance between numbers of competitions in rural and urban areas has shifted, mirroring population trends in New Zealand.

Neither of the above scenarios—a large decrease in player numbers or in typical exposure per player—would account for the differential decrease in numbers of scrum related spinal injury compared with those from other phases of play. However, at least part of the decrease in scrum related spinal injury numbers is probably due to a decrease in the number of scrums per match. Evidence from international matches indicates a long term decrease in the number of scrums per match. A comparative analysis by the International Rugby Board of international matches played in the early 1980s and the early years of the 21st century found that the average number of scrums per match had dropped from 31 to 19. In Bledisloe Cup matches, the number of scrums showed a decrease of 17% per decade from 1972 to 2004, with an additional 8% decrease coincident with professionalism in 1995.[36]



Permanently disabling spinal injuries (American Spinal Injuries Association scale A to D) in New Zealand rugby union, 1976 to 2005

We do not have figures for typical numbers of scrums per match throughout all grades of rugby in New Zealand. In our experience, junior grades tend to follow the patterns of play at higher levels. We would be surprised if the number of activities per match at lower levels was following markedly different trends over time than at the higher levels, but we have no historical measurement of these. At international level, the number of scrums per match in under 19 and under 21 competitions does not differ noticeably from that at senior level. International Rugby Board statistics indicate that the numbers of scrums per 80 minutes of match play at international level in 2003 for seniors and in 2004 for under 21 and under 19 grades were 21, 22, and 22.[37] Given the above, we can attribute approximately 8-10% of the decrease in scrum related spinal injuries to a decrease in exposure as a result of fewer scrums per match in the 2001-5 period than occurred in 1996-2000.

Although the effect is not clear, the RugbySmart programme seems to have been unsuccessful in reducing the number of spinal injuries unrelated to the scrum. Compared with the relatively controlled environment of the scrum, the direction and size of forces applied to players' bodies in the tackle, ruck, and maul are much less predictable. The scrum may thus be more amenable to education based injury prevention initiatives than the tackle, ruck, or maul.

Whether the underlying risk to players (as opposed to the number of injuries observed) has changed in the tackle, ruck, and maul is difficult to determine. For example, the injury data do not take into account possible changes in the frequency of tackles and rucks in rugby. Substantial increases in both of these phases of play have been noted in professional rugby.[36] In Bledisloe Cup matches between New Zealand and Australia, the mean number of tackles per match increased from 150 (SD 32) in 1995 to 270 (25) in 2004. The average number of rucks per match increased from

WHAT IS ALREADY KNOWN ON THIS TOPIC

Spinal cord injuries, although rare on the basis of exposure per player, are a major cause of serious morbidity and mortality in rugby

WHAT THIS STUDY ADDS

The number of permanently disabling spinal injuries in New Zealand rugby has markedly decreased following the introduction in 2001 of RugbySmart, a nationwide injury prevention programme

This study exemplifies the benefit of educational initiatives in injury prevention and the need for comprehensive injury surveillance systems for evaluating such initiatives in sport

72 (18) to 178 (27) over the same period.[36] We do not know whether or to what extent such increases have been reflected in lower grades. However, if we presume that the style of play at the community level of the sport has moved in the same direction as that at the international level, the risk per event for these phases of play may have decreased. Further research into the risks and circumstances of injuries in tackles (both spinal and other injuries) is warranted.

Spinal injury rates in New Zealand and Australia

The rate of spinal injuries in New Zealand rugby in 1996-2000 was 2.7 per 100 000 players per year (including both scrum related and other injuries). The rate in 2001-5 decreased to 1.3 per 100 000 players per year. Studies from Australia have also reported annual incidences of spinal injury.[11 14 15] The rate of spinal injuries in New South Wales rugby in 1996-2000 was 5.1 per 100 000 players per year (calculated from information provided by Berry and colleagues[11]). Over the following three year period, the rate increased to 9.8 per 100 000 players per year. The Australia-wide rate in 1986-96 was 3.5 per 100 000 players per year (based on estimates of player numbers from 1985, 1990, and 1996). The rate in 1997-2002 was 3.2 per 100 000 players per year.[14 15]

The apparent differences between the rates in New South Wales and those for Australia as a whole can be partially accounted for by the fact that the denominator used for calculating the rates in New South Wales does not include school age players who play only at school and do not register with a club. The authors of these studies have pointed out that the data for player numbers on which the injury rates are based are less than optimal. In New Zealand, the denominator figure includes all school and club players. Given the limitations of the denominator data from Australia, concluding whether the risks of spinal injury involved in New Zealand rugby are lower than those in Australia is difficult.

Reported differences in rates resulting at least partly from different denominators raises an important question about which players should be included when calculating the incidence of serious spinal injuries within a region or country. In New Zealand, no case of a permanently disabling spinal injury to a player under the age of 14 has been reported in the past 30 years. Should players aged 13 and under be included in or excluded from the denominator? We have included such players in the figures presented in this paper because they are presumably at some risk of sustaining such injuries, even though none has occurred over the period studied. On the other hand, if young players have a much lower risk of spinal injury, then including the large number of these players in the count of those at risk may produce artificially low rates of spinal injuries. The variation in rates between Australian and New Zealand studies reported in this paper provides an example of the importance of agreeing definitions and procedures for the collection of such data between regions and countries.

Injury prevention in rugby

Several avenues for injury prevention are available to rugby administrators, including changes in law and educational programmes. Although changes in law can effect change quickly, we believe that research into their probable effects on patterns of match activity and the overall risk of injury to participants should be done before their introduction. Historical evidence shows that changes in law have resulted in changes in the relative frequency and nature of match activities, characteristics of players, and epidemiology of injuries that were not foreseen when the changes were introduced.[36 38]

The results presented here provide evidence that educational programmes are a viable option for decreasing the rate of serious spinal injuries in rugby union scrums. In the absence of evidence that other factors have had a major role, we believe that the RugbySmart programme has probably played a positive part in decreasing the risks to players in New Zealand of sustaining serious spinal injuries through participation in rugby.

Conclusion

Although serious spinal injuries in rugby are an emotive issue, we believe that decisions on prevention of injuries in this area should be based on evidence rather than opinion. The introduction of the RugbySmart injury prevention programme in New Zealand has coincided with a drop in the number of spinal injuries over the past five years. A decrease in injuries from scrums has been the major contributor to this reduction. Whether the programme has had an effect on injuries from other phases of play (tackles, rucks, and mauls) is unclear. Educational initiatives seem to represent a viable option for decreasing the rate of serious spinal injuries in rugby union scrums.

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Contributors: KLQ reviewed the literature, led the writing of the paper, and contributed to the design and analysis. He was responsible for the development and delivery of RugbySmart on behalf of the New Zealand Rugby Union from the inception of the programme. SMG was responsible for extracting and verifying injury data from Accident Compensation Corporation records and writing the section of the methods on the Accident Compensation Corporation system; he contributed to the writing of the remainder of the paper. He was responsible for the development and delivery of RugbySmart on behalf of Accident Compensation Corporation from 2002 onwards. WGH provided statistical advice and contributed to analyses. He provided editorial comment on a draft version of the paper. PAH led the development of the 10 point action for sports injury prevention that was used as a template for RugbySmart. She provided editorial comments on a final draft of the paper. KLQ is the guarantor.

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Competing interests: KLQ and SMG are responsible for the production of the RugbySmart programme on behalf of the New Zealand Rugby Union and Accident Compensation Corporation respectively. WGH and PAH: none declared.

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THESIS CHAPTER 3

EVALUATION OF RUGBYSMART: A RUGBY UNION COMMUNITY INJURY PREVENTION PROGRAMME

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Original paper

Evaluation of RugbySmart: A rugby union community injury prevention programme

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Abstract

RugbySmart, a rugby union injury prevention programme, was launched in New Zealand in 2001. It was compulsory for all coaches and referees to complete RugbySmart requirements annually in order to continue coaching or refereeing. After 5 years of implementation the programme partners, Accident Compensation Corporation and New Zealand Rugby Union, evaluated RugbySmart to determine its effectiveness in reducing injuries. The purpose was to evaluate the effect of RugbySmart on reducing injury rates per 100,000 players and resulting injury prevention behaviours. The RugbySmart programme was associated with a decrease in injury claims per 100,000 players in most areas the programme targeted; the programme had negligible impact on non-targeted injury sites. The decrease in injury claims numbers was supported by results from the player behaviour surveys pre- and post-RugbySmart. There was an increase in safe behaviour in the contact situations of tackle, scrum and ruck technique.

Keywords: Injury; Prevention; Rugby; Sports; RugbySmart; Behaviours

1. Introduction

The RugbySmart programme, a joint project between the Accident Compensation Corporation (ACC) and the New Zealand Rugby Union (NZRU), was implemented at the start of the 2001 rugby season (March 2001). Both ACC and NZRU contribute to the annual implementation of RugbySmart, investing in the development and delivery of the RugbySmart resources and workshops for coaches and referees. As ACC provides for the cost of rehabilitation and replacement of income it predominantly desires a reduction in the number of injuries while the NZRU wants to make the game a competitive, safe and popular sport.

RugbySmart was designed to systematically reduce the number and severity of injuries in community rugby by providing evidence-based information about injury risks and injury prevention strategies to coaches and referees. Although the strength of evidence available regarding specific risks and the efficacy of recommended practices varied widely, efforts have been made throughout the programme to update information as better evidence became available. Information was delivered to coaches and referees via video presentations combined with active participation in workshops; these were supported initially by printed materials, and subsequently by Internet resources. The number of workshops for the approximately 10,000 coaches and 2000 referees varied from region to region, reflecting differences in coach and referee numbers between more and less heavily populated areas.

Coaches were chosen to be the primary group to which RugbySmart was delivered, with the expectation that they would influence player behaviour.[1] The decision to target coaches was made on both pragmatic and evidence grounds. Firstly, delivering RugbySmart to approximately 10,000 coaches presented significantly less of a challenge than delivering it to over 130,000 players, which was consid-

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ered unfeasible. Secondly, rugby coaches have been identified by both players and coaches in New Zealand as having an important role in the communication of injury prevention information and attitudes to player safety.[2] In addition referees, who play a major role in preventing avoidable injuries during matches, were targeted by NZRU.[2] To enforce the annual compulsory nature of RugbySmart for all levels of the game from under-6 grade to senior adults, rugby teams are audited and withdrawn from competition for non-compliance of their coach or a representative in attending annual workshops. Referees who did not complete RugbySmart were not assigned matches.

RugbySmart involves coaches and referees participating in a workshop setting with focus around the RugbySmart video. The video is produced to assist consistent delivery of the injury prevention messages throughout the country. The video and other resources can be taken home by coaches after the workshop. The emphasis given to different areas has varied from year to year, with the greatest attention given to physical conditioning, technique (specifically tackling and scrummaging) and injury management. Other areas covered have included warm-up/cool-down, protective equipment (specifically mouthguards in contact situations)[3] and injury reporting.

While RugbySmart has helped to achieve a reduction in serious scrum-related spinal injuries[4] the aim of the current review was to provide a more detailed evaluation of RugbySmart in terms of the effect of RugbySmart on reducing injury rates (ACC injury incidence data combined with NZRU participation data) and resulting behaviours (ACC survey data). Currently there is little information available as to what a worthwhile change in injury rate or injury prevention behaviour for sport may be for a population-based study as there are few large prospective population-based studies in the literature.[5] This paper addresses the need for a prospective intervention study of sufficient size that can provide evidence of the effectiveness of a specific injury prevention programme.

2. Methods

Injury data were collected by ACC, a New Zealand government taxpayer-funded monopoly. The coverage by ACC provides compensation for injury costs including medical treatment, income replacement, social rehabilitation and vocational rehabilitation, and ancillary services such as transport and accommodation. A claim is made when a person seeks medical treatment from one of the 30,000 registered health professionals throughout New Zealand. When making a claim, information about the injury is collected using a standard form to ensure levels of consistency for data analysis, i.e. the registered health professional makes the diagnosis. The claim is then filed with ACC and details entered into a central database. There is no disincentive for making a claim; people are not discriminated against, risk-rated, or penalised for the number of claims made. The guarantee of personal injury coverage is offset by the restriction in ability to sue for personal injury (except in rare circumstances for exemplary damages).

There are two major categories of claims made to ACC, moderate to serious injuries claims (MSC) and minor claims. In the 2005/2006 financial year (July–June) there were 58,264 rugby claims costing ACC $NZD40,385,034. MSC represented 7.4% (4384) of the number of claims, but 77.9% ($NZD31,472,702) of the cost for 2005/2006. For this review we focused on MSC, rather than minor claims, to evaluate RugbySmart because of the high relative cost of MSC and the greater level of information collected. For evaluation of its prevention programmes, ACC also uses MSC rather than minor claims.

The injury sites that RugbySmart targets represent approximately 65% of the new rugby MSC and 73% of the cost to ACC in the 2005/2006 financial years. Specifically:

- Neck/spine (including neck/back of head/vertebrae, upper back/spine, back/spine and lower back/spine) contributing 4.2% in number and 5.4% in cost;
- Shoulder (including clavicle/blade) contributing 19% in number and 20% in cost;
- Knee contributing 25% in number and 31% in cost;
- Leg (upper and lower, excluding knee and ankle) contributing 6.4% in number and 7.1% in cost; and
- Ankle contributing 10% in number and 9.1% in cost.

A specific type of injury that has received attention is concussion. In this paper we focused on injury sites rather than diagnosis (such as concussion). Head injuries in general (e.g., injuries to the face, scalp, eye, ears and nose) were not specifically targeted, but a concussion-specific initiative was introduced in 2003/2004. This initiative was implemented through RugbySmart; a decrease in concussion MSC was observed and is reported elsewhere.[6]

Injury claims were extracted from the ACC database on 4th September 2006 and were classified by date of injury. This extraction date allowed for injuries that may have occurred late in 2005 to be included. Typically the New Zealand community rugby season occurs between March and August. There could still be players yet to seek treatment for their injury, but this is not likely, and if there are any outstanding claims, the number will be small. Since the inception of ACC in April 1974, there has been no time limit on when someone can make a claim to ACC.

To report the effect of RugbySmart using claims data, we have presented the rate of injury claims per 100,000 players per year. Player numbers were provided by the NZRU player registration system. Before 2001, player numbers were estimated from a combination of registered players and number of teams enrolled in competitions. From 2001 onwards, numbers were taken solely from the NZRU player registration database. Although the player registration system used by NZRU was changed at the start of 2001,[3] the same year as RugbySmart was implemented, this was the baseline for

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the purposes of measuring the impact RugbySmart had on MSC.

A goal of NZRU was to increase the number of people playing rugby. Assuming no change in injury rate, an increase in playing numbers that occurred would increase the absolute number of MSC to ACC.

A central part of the RugbySmart programme was using coaches as a medium to impart information in the RugbySmart workshops to players. To evaluate if this strategy of targeting coaches was successful, we surveyed adult players (males over 19), to determine if information from the RugbySmart programme was being disseminated to them. In 1996–1998 and 2005, ACC undertook surveys of self-reported behaviour of players. The effects of the RugbySmart programme were determined comparing responses from 2005 with the 1996–1998 data (noting that there were differences in methodology between the 2005 and 1996–1998 surveys). Table 1 shows the main variables collected in each survey and the survey participant characteristics.

In the surveys conducted in 1996–1998 (all pre-RugbySmart intervention) the rugby development officers (RDO's), of which there was at least one in each of the 27 regions, each visited three randomly selected clubs. RDO's surveyed no more than five players from each club (player self-completed survey forms). The response rate to individual survey questions varied from 30–82% with an average response rate per question over the 3 years of 64% (see Table 1).

The 2005 survey repeated some questions related to safe tackling, rucking and scrumming technique from the 1996–1998 surveys. Some methodological changes occurred between the surveys; typical over such a time period due to

Table 1
Characteristics of the self-reported behaviour surveys undertaken in rugby union in 1996–1998, 2001 and 2005

Year of survey	1996 (pre-RugbySmart)	1997 (pre-RugbySmart)	1998 (pre-RugbySmart)	2005 (post-RugbySmart)
n	203	135	216	571
Compliance: main response to individual questions in each survey per year (range)	57% (30–2%)	67%	68%	83% (56–100%)
Selection criteria and administration	RDO's visited three randomly selected clubs. Five players randomly selected from each club were surveyed. Self-completion forms	RDO's visited three randomly selected clubs. Five players randomly selected from each club were surveyed. Self-completion forms	RDO's visited three randomly selected clubs. Five players randomly selected from each club were surveyed. Self-completion forms	Random sample with no more than 4 players from one team at games
Size	10 page A4 booklet	10 page A4 booklet	10 page A4 booklet	Double sided A4 questionnaire
Player characteristics	Male players over the age of 19 years	Male players over the age of 19 years	Male players over the age of 19 years	Male players over the age of 19 years
Level of rugby played	Senior amateur club	Senior amateur club	Senior amateur club	Senior amateur club
Example of variables collected	Basic demographics—questions including forward or back position	Same as 1996	Same as 1997, except did not ask if player was forward or back and 7 questions on Alcohol and Rugby	Basic demographics—5 questions including forward or back position
	Activities undertaken at practice—1 questions with 5 parts			Attitudes towards key strategies of injury prevention—1 question with eight parts
	Activities undertaken at games—1 questions with 5 parts			I.C.E. knowledge and behaviour—13 questions
	Mouthguard use 1 question			Activities undertaken at practice—1 question with 6 parts
	Pre-season training—7 questions			Injury prevention information 1 question with 9 parts
	Pre-season training guides—5 questions			Roles in injury prevention 1 question with 3 parts
	Injury management and reporting—8 questions			Mouthguard use 1 question
	Knowledge of ACC advertising material—5 questions			Training guides—2 questions
				Rating of injury prevention information mechanisms—1 question with 9 parts

refinement of questions (see Table 1). While there were a number of areas explored in the various questions, we chose to focus on the parts that were used by both ACC and NZRU to evaluate RugbySmart and were key in determining continual involvement.

To examine the linear trend in claim rate per 100,000 players from 2001 to 2005, a simple Poisson regression model was developed using the GENMOD procedure in SAS (version 9.1, SAS Institute, Cary, NC). Estimated changes in claim rates were calculated as percentage changes along with 90% confidence intervals (CI) over the 5-year period.[7] We considered a worthwhile decrease in claim rates to be ≥10% (0.90) on the rationale that this would represent a noticeable decrease in injuries for both health service providers and individuals playing the sport. This met the goals for the programme for NZRU and ACC. To determine the effect for self-reported behaviour, we have presented the percentage of responses (90% CI) for each category.

3. Results

Table 2 presents the injury rates per 100,000 players by rugby season. The season is concordant with the calendar year in the southern hemisphere. The injury rates in 2005 in general decreased compared to 2001 for targeted injuries and dental claims; however, non-targeted areas did not decrease by 2005. There was a worthwhile effect for targeted MSC but not for non-targeted MSC.

When rates for specific injury sites were analysed and grouped by similar sample sizes, some sites that were targeted, such as the knee, neck/spine and leg (excluding knee and ankle), had decreased by 2005. Although ankle injuries were targeted, the change in claim rates was negligible. Shoulder injuries fell just short of the threshold for a worthwhile effect. Injury sites that were not targeted, however, did not decrease—for example, foot/toe injury claim rates increased over the evaluation period. The rate of increase for one non-targeted injury site, finger/thumb/hand/wrist exceeded the 10% (0.90) threshold.

The 2005 survey data on practice behaviour and injury management supported the change observed in injury sites reported in Table 2. Behaviour at practice as reported by players (see Table 3) showed worthwhile effects for safe tackle, safe ruck, safe scrum and cool-down when comparing 2005 with 1996–1998. The only behaviour area that did not show an effect was warm-up which had already achieved 100% in 1998 and was 98% in 2005.

Table 2
Changes in ACC rugby moderate to serious injury claim rates from 2001 to 2005

Injury site	Rate per 1,000,000 players					Five year trend in injury rate (90% CL)
	2001	2002	2003	2004	2005	
Neck/spine[a]	122	106	108	110	93	0.77 (0.62–0.97)
Shoulder[a]	473	455	486	496	412	0.91 (0.82–1.01)
Knee[a]	675	654	623	583	565	0.79 (0.72–0.87)
Leg (excluding knee and ankle)[a]	175	154	182	166	137	0.81 (0.68–0.97)
Ankle[a]	244	261	273	262	243	0.99 (0.86–1.14)
All[a]	1689	1629	1671	1616	1449	0.85 (0.81–0.91)
Finger/thumb/hand/wrist[b]	376	385	399	369	342	0.89 (0.79–1.00)
Arm/elbow[b]	153	169	161	168	156	1.01 (0.84–1.21)
Head/face/eye/ear/nose[b]	131	124	141	153	142	1.20 (0.98–1.46)
Chest/abdomen/pelvis[b]	83	86	93	80	79	0.91 (0.71–1.17)
Foot/toe[b]	26	36	34	44	54	2.29 (1.57–3.34)
All[b]	770	800	828	815	773	1.01 (0.93–1.09)

[a] Targeted body site—moderate to serious claims.
[b] Non-targeted body site—moderate to serious claims.

Table 3
Behaviour at practice as reported by players

Behaviour	1996			1997			1998	2005		
	Fwds (%), $n=105$	Back (%), $n=96$	Total (%) (90% CI), $n=203$	Fwds (%), $n=79$	Back (%), $n=55$	Total (%) (90% CI), $n=135$	Total (%) (90% CI), $n=216$	Fwds (%), $n=318$	Back (%), $n=250$	Total (%) (90% CI), $n=573$
Warm-up	84	84	84 (80–88)	84	82	83 (78–88)	100	98	98	98 (97–99)
Cool-down	49	48	48 (42–54)	66	53	61 (54–68)	67 (62–72)	78	83	80 (77–83)
Safe tackle	45	46	45 (39–51)	48	51	49 (42–56)	56 (50–62)	84	87	86 (84–88)
Safe ruck	39	40	39 (33–45)	39	36	38 (31–44)	41 (36–46)	69	68	68 (65–71)
Safe scrum	70	50	61 (55–67)	73	45	62 (55–69)	59 (54–64)	93	59	78 (75–81)

Fwds: forwards; back: backs.

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4. Discussion

Educational strategies have been used in a number of public health areas, such as diabetes and cardiovascular disease, to reduce the risk of illness by changing participants' knowledge and consequent behaviours. For example, Kirk et al.[8] reported that exercise consultation was more effective in stimulating exercise behaviour change in the short term than a standard exercise leaflet in people with Type 2 diabetes. Within rugby there has been literature published on injury incidence at both community and professional level of the sport, but few papers have evaluated the effect of injury prevention programmes. The RugbySmart programme provided a unique opportunity to evaluate the impact of an educational strategy for sports injury prevention that was focused at the community level and implemented throughout a country. We are unaware of any other programmes around the world that have combined a nationwide injury prevention intervention with nationwide injury data collection. As well as injury data, surveys of the knowledge, attitudes and behaviours of participants have been conducted, which has permitted the effect of RugbySmart to be evaluated at various levels. While the RugbySmart evaluation has limitations that need to be mitigated, the RugbySmart programme has been designed so that its impact can be continually evaluated.

Analysis of the injury rates per 100,000 players has shown worthwhile reduction in claims for targeted areas, but little impact on non-targeted claims. This provides a useful comparison; if non-targeted areas had decreased at a similar rate to targeted areas then the likelihood of factors other than RugbySmart contributing to the decrease would be higher. This was further supported when injury sites were analysed. In an ideal setting player exposure would have been used to calculate rates. However, we do not believe the exposure has changed markedly over the study period.[4] The cost of determining exposure for community level injury prevention, particularly across an entire country covering multiple grades and competitions would make such regular collection of exposure data prohibitively expensive. The benefit of the ACC system is that claims are collected as its business requirement required by government and as such can be used for analysis of injury prevention initiatives.

The self-reported survey results of players indicated a level of success for the RugbySmart programme in increasing injury prevention behaviour, i.e., the players, led by the coach, incorporated more of the desired prevention behaviours into training and matches. The injury sites targeted (see Table 2) are parts of the body associated with the contact aspects of the game (such as scrums as shown in Table 3) and we presume decreases in injuries to these areas reflect improvements in player technique. The increases in self-reported behaviour are consistent with the material provided in RugbySmart.

In hindsight the evaluation of RugbySmart would have benefited from a baseline established in 2000 just prior to RugbySmart being introduced in 2001, consistent methodologies between studies and not having a change in player registrations in 2001. Inconsistent methodology has been widespread across community intervention programmes. The challenge for the RugbySmart programme is to keep the same methodology for the next 5 years to allow valid comparisons to be made.

In conclusion there has been an observed decrease in injury claims per 100,000 players in areas RugbySmart specifically targeted. This decrease is supported by the improvement in injury prevention behaviour of players.

Practical implications

- Workshops can be used to communicate injury prevention information on a nation-wide basis.
- Community-focused injury prevention can be successful.
- To increase acceptance of injury prevention information, the content needs to be suitable for the audience with plain language take home messages.
- Plans for evaluation should be built into programme design.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jsams.2008.01.002.

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THESIS CHAPTER 4

AN EVALUATION OF MOUTHGUARD REQUIREMENTS AND DENTAL INJURIES IN NEW ZEALAND RUGBY UNION

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ORIGINAL ARTICLE

An evaluation of mouthguard requirements and dental injuries in New Zealand rugby union

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Objectives: To document the effects of compulsory mouthguard wearing on rugby related dental injury claims made to ACC, the administrator of New Zealand's accident compensation scheme.

Methods: An ecological study was conducted. Estimates of mouthguard wearing rates were available from prospective studies conducted in 1993, 2002, and 2003. Rugby related dental injury claims were available for the period 1995–2003. Player numbers were available from 1998. Mouthguard wearing was made compulsory during match play for rugby players at under 19 level and below at the beginning of the 1997 season, and for all grades of domestic rugby at the beginning of the 1998 season. Greater powers of enforcement were provided to referees at the beginning of the 2003 season.

Results: The self reported rate of mouthguard use was 67% of player-weeks in 1993 and 93% in 2003. A total of 2644 claims was reported in 1995. There was a 43% (90% confidence interval 39% to 46%) reduction in dental claims from 1995 to 2003. On the reasonable assumption that the number of players and player-matches remained constant throughout the study period, the relative rate of injury claims for non-wearers versus wearers was 4.6 (90% confidence interval 3.8 to 5.6). The cumulative savings in claim costs compared with the cost per year if claim numbers had remained constant from 1995 is $1.87 million NZD.

Conclusion: Although ecological studies have acknowledged weaknesses, the findings provide evidence that mouthguard use is a simple and effective injury prevention strategy for rugby players. The use of mouthguards for all players in both matches and contact practice situations is strongly recommended.

Rugby union is a widely played physical contact sport that enjoys particular popularity in the United Kingdom, France, South Africa, Australia, New Zealand, and some Pacific Island nations. Injuries are common, primarily because of the physical contact during tackles, rucks, scrums, and mauls. A number of studies have described the injury epidemiology of specific cohorts of rugby players.[1–7] Typical patterns of injury have emerged from these studies. Overall, the findings suggest that injuries from rugby are distributed throughout the body. Most reported injuries have been to the soft tissues of the body (sprains, strains, and haematomas), and the tackle has generally been reported as the phase of play in which injuries most commonly occur. It appears that the rate of injury increases with higher levels of play,[1 2 4 8] perhaps because of the greater energy developed in the contact phases of the sport between larger and more powerful athletes.[9] Specific injury types, such as spinal injuries, have also received attention; the mechanisms associated with these have been documented through case reports and case series studies.[10]

Various pieces of protective equipment are permitted within the laws of the game of rugby.[11] These include padded headgear, shoulder pads, shin guards, and mouthguards. Little research on the effectiveness of the permitted equipment in preventing injuries has appeared in the scientific literature, although some appraisals of the various types of equipment have appeared.[12–18] Garraway and colleagues[4] speculated that protective equipment may lead to an increase in competitiveness in the contact phases of the sport, and a subsequent increase in injury rates, and called for a moratorium on the use of such equipment in competitive matches until the International Rugby Board (IRB) had assessed its effect on player morbidity.

At present, the wearing of mouthguards is permitted in rugby, but under the IRB laws of the game their use is not compulsory. In New Zealand a "domestic safety law variation" was introduced over the 1997–1998 seasons to require all players to wear mouthguards during matches. In 1997, mouthguard use became mandatory for all players at under 19 level and below, and in 1998 this was extended to players of all grades (levels of play). Although mouthguard use was mandated, there was no specific sanction available to the referee under the domestic safety law variation to ensure compliance with this law. A minor modification to the laws at the beginning of the 2003 season allowed referees greater powers in enforcing the laws, including the ability to send players from the field should they not be wearing a mouthguard in the prescribed fashion. These domestic safety law variations apply to all rugby played in New Zealand except for international competitions. Mouthguard use during team practices is optional, although it has been promoted through educational seminars. The primary purpose of this study was to document the effects of these rugby law changes in mouthguard use on rugby related dental injury claims made to ACC, the administrator of New Zealand's accident compensation scheme. A secondary purpose was to estimate the relative risk of dental injury claims for wearers and non-wearers of mouthguards.

METHODS

ACC is a public sector organisation charged with the administration of New Zealand's 24 hour, no fault accident compensation and rehabilitation scheme. ACC is required by statute to endeavour to prevent injuries, and compensate those in New Zealand who are injured. ACC insures all forms of personal injury including worker's compensation and

Abbreviations: IRB, International Rugby Board; NZRU, New Zealand Rugby Union; RIPP, Rugby Injury and Performance Project; RISP, Rugby Injury Surveillance Project compulsory third party insurance for motor vehicle injuries. Injury claims are paid out over time in the form of income replacement, medical costs, and rehabilitation expenditure.

The criteria for the rugby related dental injury claims reported in this study were that the claim had a sport code of rugby union (ACC Sport Codes = 25 or 79), an activity before the injury of recreation or sporting activity (ACC ap Code = 19), and a forecast injury group of dental treatment (ACC fg = 15). Hence dental injuries that occurred during rugby practices or matches could become claims. To allow comparisons in dental injury claim numbers from year to year to be made, the above criteria for claims acceptance were applied retrospectively to the ACC records. Information on rugby related dental injury claims was obtained from ACC over the period 1995–2003. The number of rugby players in New Zealand was obtained from New Zealand Rugby Union (NZRU) records.

Typical rates of mouthguard use were obtained from studies that surveyed mouthguard wearing rates before (1993)[19] and after (2002 and 2003)[8 20] the law changes took place. These studies used the same basic design for the collection of information, and the distribution of male players across the grades was similar. However, there were differences in the wording of the questions about mouthguard use.[8 19 20] Players were selected for the studies, and regular telephone interviews were used to enquire about exposure to rugby, injuries sustained, and protective equipment used.

The 1993 study involved a cohort of players from Dunedin, and was entitled the New Zealand Rugby Injury and Performance Project (RIPP). The methods[21] and results[1 19 22 23] from RIPP have been reported. In summary, 345 players (258 male and 87 female) from a range of grades were contacted weekly by telephone throughout an entire rugby season. Use of mouthguards was reported for 327 players (240 male and 87 female) actively participating in rugby through the season.[19] Active participation in rugby was defined as participation in at least one team practice or match during a particular week. The question relevant to mouthguard use asked in RIPP was: ''Did you use any protective gear or strapping during team practice(s) or games last week? If yes, what did you wear? ''Mouthguard'' was one response category. Thus the rate reflected whether the player used a mouthguard during matches or team practices or both, but did not distinguish the rate of wearing during matches from that during practices.

Although the 2002[20] and 2003[8] Rugby Injury Surveillance Projects (RISPs) also used telephone interviews, there were a number of differences in design from the RIPP study. Firstly, players were selected from throughout New Zealand, and secondly the distribution of players by grade differed from that in RIPP; in the RISPs there were no female players.

The surveillance projects coincided with the modification in the powers available to the referee to mandate the use of mouthguards during matches noted above. The RISP studies used the NZRU player registration database to obtain representative samples of players aged 16 and over from various grades throughout the country. Different samples were obtained for each year. In 2002, 560 players were placed into two groups, one of which was contacted weekly, and the other was contacted fortnightly. The relevant question asked was ''Did you wear any protective gear or strapping?'' ''Mouthguard'' was one response category. This was asked for each game played and each practice attended. In 2003, information was collected from 774 players by weekly telephone interviews. The following question was asked: ''Did you wear a mouthguard?'' with the response categories ''Yes/No/Did not answer''. This was asked for each game played but not asked for practices.

For the purposes of estimating relative risks of dental claims for wearers compared with non-wearers of mouthguards, the female players in RIPP were excluded from the analysis. To estimate the relative risk of dental injury claims for non-wearers compared with wearers of mouthguards, we assumed that the rates of injury for wearers and non-wearers did not change between 1993 and 2003. We then solved the two simultaneous equations provided by the rate of claims for the two years to obtain the rates: (proportion of wearers) × (rate of injury for wearers) + (proportion of non-wearers) × (rate of injury for non-wearers) = rate of claims. Confidence intervals for the relative risk were estimated by simulation: random error was added to the proportions consistent with the sample size from which they were derived (assuming a binomial sampling distribution), random error was added to the claim rates consistent with their totals (assuming a Poisson sampling distribution), and the equations were solved again; this process was repeated 400 times, and the confidence intervals were derived from the resulting values by assuming that the logarithm of the relative risk was normally distributed.

RESULTS

Mouthguard use

Over the period 1993–2003, the self reported rate of mouthguard use among male rugby players increased by 26%.[8 19] Through the 1993 season, mouthguards were worn for 67% of player-weeks among the 240 men in a cohort of 327 Dunedin players from various grades who were enrolled in the RIPP.

In 2002, mouthguards were reported to be worn by players in the RISP in 85% of games and 38% of practices. In 2003, they were reported to be worn in 93% of games. Mouthguard use during practices was assessed at the conclusion of the 2003 season. Most (59%) players reported wearing mouthguards during practices at least sometimes. Of these players, 46% reported that they always wore mouthguards during practices involving contact.

Player numbers

Although accurate player numbers were not collected before 1998, the consensus view of NZRU staff was that they had remained reasonably constant throughout the mid-1990s. From 1998 onwards, numbers ranged between 120 000 and 130 000 (table 1). There was a recorded decrease in players of 8800 between 2000 and 2001. This coincided with a change in the method of measuring player numbers. Before 2001, player numbers were estimated from a combination of registered players and number of teams enrolled in competitions. From 2001 onwards, numbers were taken solely from the NZRU player registration database. From 2001 to 2003 there was little change in player numbers.

Table 1 Number of rugby players in New Zealand by year

Year	Player numbers
1998	121900
1999	129800
2000	128700
2001	119900
2002	121600
2003	120900

Source: New Zealand Rugby Union. Player numbers are rounded to the nearest hundred.

Dental injury claims

Since the introduction of mandatory mouthguard wearing among New Zealand rugby players, there has been a 43% (90% confidence interval (CI) 39% to 46%) reduction in rugby related dental injury claims to ACC (fig 1). In 1996, the year before mouthguards became compulsory for under 19 grades, 2690 rugby related dental injury claims were made to ACC. This represented a 2% increase in number of claims over the previous year. In 1997, this number dropped to 2316, a reduction of 14%. The following year, there were 2136 claims, a further 8% reduction. From 2002 to 2003, when referees were provided with additional sanctions to enforce the wearing of mouthguards, there was a reduction in claims of 5%. The cumulative number of claims saved compared with the number of claims per year if claim numbers had remained constant from 1995 is 5839. The average cost of a dental injury claim to ACC is $321 NZD. The cumulative savings in claim costs compared with the cost per year if claim numbers had remained constant is $1.87 million NZD. Using the methods and assumptions outlined above, the estimate for the relative risk of claims for wearers was 4.6 (90% CI 3.8 to 5.6) times that of non-wearers.

Although claims could result from either matches or practices, mouthguard use is only compulsory during matches. The 2003 RISP study of rugby injuries in New Zealand[8] indicated that injuries to the teeth and jaw made up only 1% of total injuries reported in both practices and matches. The rate of orofacial injuries was 0.7 per 1000 player-hours during matches, and 0.1 per 1000 player-hours during practices.

DISCUSSION

As with other studies using ecological methods, caution must be taken to ensure that the conclusions reached are not compromised by ecological fallacies, confounding, or bias. As far as possible, efforts have been made to account for other factors that may have contributed to the results observed. Although it is tempting to take the above findings at face value, issues that may have biased the findings must be addressed. Firstly, accurate records of player numbers were not available over the early period of the study. A large reduction in player numbers and/or in the typical amount of rugby exposure per player would obviously weaken the inference that the observed decrease in dental injury claims was associated with increased mouthguard use. Although the NZRU did not have all players recorded on a registration database throughout the study period, it unlikely that player numbers changed substantially over that period, and any changes would certainly not have been of the order of a reduction of 40%. Since 1998, variations in recorded numbers have been within 10%, with the difference being primarily associated with a change in measurement methods as described above.

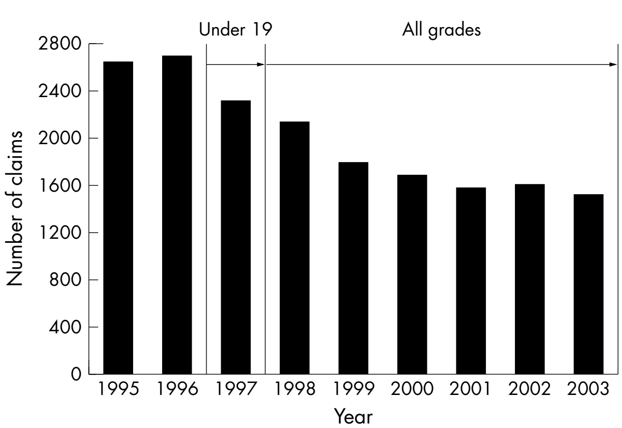

Figure 1 Rugby related dental injury claims in New Zealand.

Secondly, the rate of mouthguard wearing in players throughout New Zealand in 1995 was assumed to be the same as that recorded for a sample of players from Dunedin in 1993. If the actual difference in wearing rates between the sample and the population over this time was large, the true relative rate of injuries to wearers and non-wearers would also be different from that estimated. A related problem is the fact that the wearing rates in practices and matches could not be distinguished in the RIPP study. The data collected on player wearing rates during practices at the end of the 2003 season indicate that these rates are substantially lower than for matches. In addition, mouthguard wearing rates were derived from studies that differed in terms of the questions used to investigate the rate of mouthguard wearing.

A fourth factor that may have had an effect is the type of mouthguard typically worn. If there were differences in the protection afforded by one type of mouthguard compared with another, and the proportions of players wearing the various types changed substantially, the relative risk of injury in the players who wore mouthguards may have changed over the period of the study. Finally, changes to the nature of the sport itself—for example, a large increase or decrease in the typical numbers of tackles per match—may have altered the risk of being injured. However, whether any such changes would have differentially modified the risk for non-wearers compared with wearers is not known.

To confidently assess the relation between mouthguard use and dental injuries would require much larger sample sizes than have been used in most of the previous studies on mouthguard use in rugby.[24–31] A 1987 study by Blignaut and coworkers[25] that examined 321 players who participated in 555 player-matches concluded that there was no difference in oral injury rates between wearers and non-wearers of mouthguards. However, given the size of the sample and the frequency of oral injuries in rugby, the validity of such a conclusion must be questioned. A retrospective study in England examined self reported orofacial injuries in 114 senior players and 69 junior players.[32] Among the senior players, 64 orofacial injuries were reported in the 54 players who did not typically wear mouthguards, compared with 18 injuries in the 60 players who did. This yields a relative rate of injury of 3.95 (90% CI 2.5 to 6.1) for non-wearers versus wearers. Among the junior players, 23 orofacial injuries were reported by 24 non-wearers and 16 injuries by 45 non-wearers. The relative rate of injury among the junior players was 2.7 (90% CI 1.6 to 4.6) for wearers versus non-wearers. Although the sample size in this study was small, the risk estimates are consistent with the relative risk calculated in the New Zealand situation.

The relative effectiveness of the various types of mouthguards available has also received little attention. Reviews of the role of mouthguards in preventing dental injuries in sports have suggested that dentist fitted mouthguards offer superior fit, comfort, and ability to breathe over the mouth fitted type.[33] Chalmers[12] recommended that mouthguards should be used in both practices and games and replaced often (about every two years). He stated that, although a number of factors would necessarily be taken into account in choosing a mouthguard (such as relative cost, age of the player, and the effectiveness of the different types), players in higher grades and in more vulnerable positions should invest in a dentist fitted mouthguard. However, despite the belief of dental experts that dentist fitted mouthguards offer superior protection because of less variability in thickness during the

What is already known on this topic

There is a lack of epidemiological evidence about the effect of wearing mouthguards on dental injuries in contact sports.

What this study adds

The introduction of compulsory wearing of mouthguards for rugby players in New Zealand has been associated with a 43% reduction in rugby related dental injury claims. The relative risk of making a dental injury claim for non-wearers was estimated to be 4.6 times that of wearers.

process of construction and greater coverage of the teeth,[33] there have been no studies with sufficient sample sizes and injury numbers to confirm a difference in rugby injury rates in practice. For example, in a study of 120 rugby players, 55 were provided with mouth fitted "boil and bite" type mouthguards, and 65 were provided with laboratory made mouthguards. Of the 98 players who were followed up at the end of the season, none had sustained damage to the teeth while wearing either type of mouthguard.[28] Further research examining the rates of claims among players wearing various types of mouthguards would help to clarify the relative effectiveness of the mouthguards currently available to players.

The logistics of further investigating the effects of wearing mouthguards, or comparing one type of mouthguard with another, would be less complicated in an experimental study than an observational study, especially with current wearing rates reported to be about 93% of player-weeks, but in the light of the findings presented, it is highly unlikely that ethical approval would be granted to assign players to a non-wearers group.

The changes to the laws of the sport in New Zealand have been supported by educational initiatives. Since 1996, all New Zealand coaches and referees of all grades of tackle rugby (typically under 9 and above) have been required to attend compulsory safety seminars. From 2001 onwards, these seminars have gone by the name "RugbySmart", and have focused on aspects of injury prevention such as technique, physical conditioning, injury management, and protective equipment (http://www.acc.co.nz/injury-prevention/safe-in-sport-and-recreation/sports-codes/rugby/rugbysmart10points/). Mouthguard use as a means of preventing dental injuries has been promoted in these seminars and their accompanying resources.

A recent injury surveillance report indicates that, although the rates of both mouthguard wearing and orofacial injuries during practices are substantially lower than during matches, players spend more time in practices than in games.[8] Although the wearing of mouthguards is optional during practices, we recommend that they should be worn during practices that involve contact.

The relative claim rate of 4.6 for non-wearers compared with wearers calculated above should be interpreted with some caution because the rates of mouthguard wearing were derived from studies that asked about mouthguard use in slightly different ways. In addition, there was a lack of certainty about player numbers in New Zealand and mouthguard wearing rates on a year by year basis. Even so, it is a step towards estimating the protective effect of mouthguards in rugby, and the large number of both players and claims allows greater confidence to be placed in the effect of mouthguards than was previously possible. The finding that mandating mouthguard use in New Zealand rugby has coincided with a 43% reduction in dental injury claims indicates that compelling players to wear mouthguards represents a simple and effective strategy to prevent dental injuries in rugby.

CONCLUSION

Despite the acknowledged weaknesses in ecological study designs, the findings presented provide evidence that compelling rugby players to wear mouthguards is a simple, effective injury prevention strategy. On the basis of the New Zealand experience with compulsory mouthguard use and the commensurate decrease in dental injuries, we strongly endorse mouthguard use for rugby players at all levels in both match and contact practice situations.

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K L Quarrie, S M Gianotti, D J Chalmers, *et al*. An evaluation of mouthguard requirements and dental injuries in New Zealand rugby union (*Br J Sports Med* 2005;**39**:650–4). A number of errors were spotted following publication of this article. The errors are as follows:

In the results section under the sub-heading "Dental injury claims" "wearers" and "non-wearers" are juxtaposed. The sentence should read:

Using the methods and assumptions outlined above, the estimate for the relative risk of claims for non-wearers was 4.6 (90% CI 3.8 to 5.6) times that of wearers.

In the discussion section, the final two sentences contain errors. The penultimate sentence should read:

Among the junior players, 23 orofacial injuries were reported by 24 non-wearers and 16 injuries by 45 wearers.

In the final sentence of the fourth paragraph the words "wearers" and "non-wearers" are again in the wrong order. The last sentence of the fourth paragraph should read:

The relative rate of injury among the junior players was 2.7 (90% CI 1.6 to 4.6) for non-wearers versus wearers.

The authors apologise for these errors.

THESIS CHAPTER 5

TACKLE INJURIES IN PROFESSIONAL RUGBY UNION

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Tackle Injuries in Professional Rugby Union

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Background: The tackle is the most dangerous facet of play in rugby union, but little is known about risk factors for tackle injuries.

Purpose: To estimate the injury risk associated with various characteristics of tackles in professional rugby union matches.

Study Design: Descriptive epidemiology study.

Method: All 140 249 tackles in 434 professional matches were coded from video recordings for height and direction of tackle on the ball carrier, speed of tackler, and speed of ball carrier; injuries were coded for various characteristics, including whether the tackler or ball carrier required replacement or only on-field assessment.

Results: There were 1348 injury assessments requiring only on-field treatment and 211 requiring player replacement. The inciting event and medical outcomes were matched to video records for 281 injuries. Injuries were most frequently the result of high or middle tackles from the front or side, but rate of injury per tackle was higher for tackles from behind than from the front or side. Ball carriers were at highest risk from tackles to the head-neck region, whereas tacklers were most at risk when making low tackles. The impact of the tackle was the most common cause of injury, and the head was the most common site, but an important mechanism of lower limb injuries was loading with the weight of another player. Rates of replacement increased with increasing player speed.

Conclusion: Strategies for reducing tackle injuries without radically changing the contact nature of the sport include further education of players about safe tackling and minor changes to laws for the height of the tackle.

Keywords: football; rugby; risk factors; injury; prospective study

Rugby union (rugby), a popular type of full-contact football, is the game from which American football evolved. The worldwide governing body of rugby, the International Rugby Board (IRB), lists 95 countries in its world rankings, although in most countries it is a minor sport. Rugby is most commonly played between 2 teams of 15 players for 2 periods of 40 minutes. The anthropometric and physical characteristics of each position have been described previously.[10,24] In general, forwards (positions 1-8), who are typically taller and heavier than backs,[26] are primarily responsible for contesting possession of the ball. Backs (positions 9-15), who are typically quicker than forwards,[26] are mainly charged with gaining field position and scoring points.[26] Each team is permitted up to 7 replacements, either for injuries or tactical purposes.

The tackle is the most dangerous facet of play in rugby, accounting for up to 58% of all game-related injuries.[2,4,6,9,13,30] Tackles also are associated with a large proportion of the most serious head and spinal injuries.[1,17,25,26] Prospective cohort studies of rugby injury epidemiology have documented that tackle injuries are distributed throughout the body for both carriers and tacklers.[4,13] A recent study of tackle injuries among professional players reported that concussion and cervical nerve root injuries were the most common injuries to tacklers, whereas shoulder injuries resulted in the greatest loss of participation.[6,7] Thigh hematomas were the most common injuries to ball carriers, with anterior cruciate ligament injuries resulting in the greatest amount of missed play.[6]

Factors moderating the risk of injury in the tackle have not been studied extensively, and the findings of the existing research are not always consistent. Tackles to the

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head/neck region and double tackles (2 players tackling the ball carrier) were identified through early case reports as risk factors for spinal injuries.[27,28] The tackler appeared to be at slightly greater risk than the ball carrier in some studies[5,6,9,15] but not others.[4] In one case series,[15] most injuries occurred in tackles from behind or from the side, but in another case series,[32] tackles from the front, which stopped the ball carrier, produced more injuries. In a prospective study of injuries to professional rugby players, front-on tackles produced most injuries to the tackler, whereas injuries to the ball carrier were most common from side-on tackles.[6]

To date, studies of injuries in tackles have had a number of limitations. First, information about those tackles that do not result in injury has not been provided.[15] Thus, relative rates of injury for specific types of tackle have not been available. In addition, the relatively small scale of the case series studies presented to date[15,32] has meant that a large degree of uncertainty remains with respect to the inciting events, or mechanisms, of tackles that result in injury. No medical information describing the circumstances of injuries in the tackle (eg, site, type, and severity) was provided from these case series studies.[15,32] Among those prospective studies examining tackle injuries that have provided medical information and the effect of injury on subsequent participation, the degree of information about the circumstances of the tackle has been limited.[6,7,14,30] Recognition of these limitations has prompted calls for studies that collect data about all tackles rather than just those that result in injury,[15] for the use of video data to examine the specific circumstances of tackle injuries,[6] and for studies to take into account both the frequency with which injuries occur and their subsequent effect on the participation of players.[12]

To gain a deeper understanding of the impact of tackle injuries in rugby, information is required about (1) how frequently specific characteristics of tackles are associated with injury, (2) how common particular tackle characteristics are in the sport, (3) what inciting events are commonly associated with specific types of injury, and (4) what burden the resulting injuries place on players and teams. The purpose of this study was to provide new knowledge about the risks and circumstances of tackle injuries in rugby by undertaking a large-scale prospective study of tackle injuries using video data. All tackles were coded, thus overcoming one of the main limitations of the work to date. The video data for tackles resulting in injury was cross-linked to medical data to provide information about inciting events and the burden of injuries for a subsample of the tackles.

METHODS

Video Data

To investigate aspects of the tackle thought to modify risk of injury to professional rugby players, we examined all matches in each professional competition in which New Zealand teams competed from 2003 to 2005. These

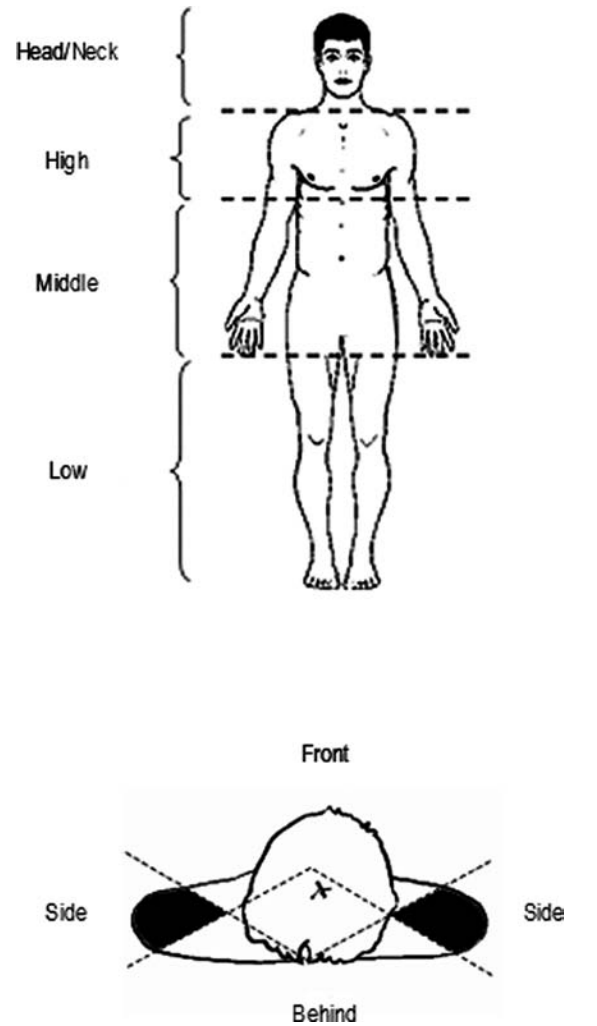

Figure 1. Tackle height and direction coding.

matches represented a convenience sample, with sufficient injuries to allow reasonably narrow confidence intervals (CI) around rate estimates in most cases. A commercial coding company (Verusco Technologies, Palmerston North, New Zealand) used proprietary software with video recordings to code all tackles in the following televised professional rugby match series: New Zealand National Provincial Championship 2003-2005 (n = 144); Super 12, 2003-2005 (n = 207); 2003 Rugby World Cup (n = 47); Tri-Nations 2003-2005 (n = 18); and all other international (test) matches played by the New Zealand national team (the All Blacks) 2003-2005 (n = 18). Coding of the 434 matches included information about date, teams, players, and positions. The resulting video database allowed each tackle to be reviewed on demand by querying any of the coded categories. A selection of examples of tackle injuries from the data for this paper has been provided online at the AJSM website at http://ajs.sagepub.com. The tackle characteristics coded included tackle height and direction (Figure 1), movement type of the ball carrier and tackler (stationary, walk, jog, run, sprint), and number of players in the tackle. The classification of movement type followed conventions previously described for time-motion analyses of rugby players.[8,11]

The 2002 Super 12 competition was used as a pilot study to train the coders. Sixty-nine matches were coded according to a schema developed specifically for this project. The head coder at Verusco Technologies undertook consistency checking. In cases where the circumstances of the tackle were ambiguous or poorly captured on the video record, the head coder made the final decision about the circumstances of the tackle, for example, the height and direction of the tackle and the relative movement type of the players involved. In professional rugby matches, multiple views of the match are televised, which helps to increase the accuracy of the coding.[20] We selected 6 matches at random following the completion of coding and had them recoded by the head coder to assess the influence of coder reliability. Kappa coefficients (number of tackles = 1986 in each case) were calculated for tackle height ($\kappa = 0.65$; 90% CI: 0.62-0.67), direction ($\kappa = 0.85$; CI: 0.83-0.87), tackler movement ($\kappa = 0.58$; CI: 0.56-0.61), and carrier movement ($\kappa = 0.65$; CI: 0.62-0.67). The lower the κ, the greater the attenuation of the effect. The rate ratios can be corrected for the attenuation resulting from the κ value by raising the rate ratio to the power of 1 over the appropriate κ.

Medical Data

Information captured for medical injuries included injury date, player, phase of play, injury site, type, and severity (days unavailable for selection).[14] Information from the video coding was cross-linked with a purpose-built New Zealand Rugby Union database (RugbyMed) by matching player name, date, and phase of play. There were 738 injury assessments and injury replacements to New Zealand players coded from the video records, 38% of which (281 injuries) were matched to RugbyMed injury claims. For these 281 injuries, the inciting event[16,22] was coded by one of the authors (K. L. Q.) according to whether the injury was the result of an impact between players, loading of the body by other players, the player falling/impacting the ground, or unable to be determined from the video record. Details recorded about impact injuries between players included which body parts were involved in the collision. Injury site was coded according to the categories outlined in the consensus document for injury data collection in rugby union by Fuller et al[14] and subsequently grouped into 3 body regions: the head/neck (head/face/neck/cervical spine); the upper body (shoulder/torso/arm/wrist/hand); and the lower body (hip/groin/thigh/knee/lower leg/ankle/foot).

Tackle and Injury Definitions

For the present study we defined tackles as follows: a *tackle* occurred when a ball carrier was contacted (hit and/or held) by an opponent without reference to whether they went to the ground. This differs from the definition of tackles under the laws of the game,[18] which specify that the ball carrier must be brought to the ground. We included events in which an opponent made substantial contact with a ball carrier or noticeably affected the movement of the ball carrier but did not complete a tackle. We further modified the definition to distinguish between tackles and what we termed "tackle events." A tackle occurred for every tackler contacting a ball carrier, whereas a *tackle event* occurred whenever a ball carrier was contacted by 1 or more opponents; thus, a tackle event could have more than 1 associated tackle.

Injury assessments were defined as tackles or tackle events resulting in a player obtaining medical attention on the field or being treated in the "blood bin" but subsequently continuing to participate in the match. *Injury replacements* were defined as injuries resulting in a player leaving the field for the remainder of the match. *Medical injuries* were defined as those injuries for which medical information for New Zealand-based players was entered into RugbyMed by team physicians. Medical injuries accrued medical costs and thus required an injury claim to be lodged into New Zealand's national injury insurance scheme and included, but were not limited to, those injuries observed on video.

Injury rate was defined as the incidence of injuries either per 1000 player-hours or per 1000 tackles (or tackle events). *Severity* was defined as the number of days an injured player was unavailable for selection for matches.[14] *Injury burden* was calculated as the rate of injury either per 1000 player-hours or per 1000 tackles multiplied by the severity of injury. Whereas Fuller and colleagues have called these measures *risks*,[12] the term risk has a specific meaning in injury epidemiology,[19] we have therefore chosen "injury burden" to avoid confusion as to which meaning of risk was intended.

Statistical Methods

Analyses of injury rates were performed using the generalized linear modeling procedure (Proc Genmod) in SAS (Version 9.1, SAS Institute, Cary, NC). To estimate rates of injury for tacklers per 1000 tackles, each tackle was coded with a binary-dependent variable representing injury replacement. A binomial response distribution was used. Similar analyses were performed to estimate injury rates for ball carriers by coding tackle events rather than tackles. To estimate rate of injury for tacklers or ball carriers per 1000 player-hours, the dependent variable was the sum of tackle injuries for each level of the tackle characteristic per match, and the Poisson response probability distribution was used. Separate analyses were performed for each potential risk factor (tackle height, direction, player movement speed, number of tacklers, player position) as a single main effect. The effect of tackle height, direction, and tackler movement on injury rate to ball carriers was estimated only for tackle events involving a single tackler. A logarithmic link function was used to express effects as rate ratios.

Examination of the influence of the repeated observations on individuals was performed by conducting generalized estimating equation analyses for tackle height, direction, and tackler speed and comparing the CIs obtained with those from the corresponding generalized

TABLE 1
Effect of Tackle Event Characteristics on Ball Carrier Replacement Injuries[a]

	Tackle Events per Match, Mean ± SD	Replacement Rate Per 1000 ...		
		Tackle Events	Player-Hours	Player-Hours as a Percentage, %
Total[b]	203 ± 29	1.1 (1.0-1.3)	5.8 (4.9-6.8)	100
Number of tacklers[b]				
1	99 ± 17	1.2 (1.0-1.5)	3.1 (2.4-3.8)	53 (45-61)
2	84 ± 16	1.2 (0.9-1.5)	2.5 (1.9-3.2)	43 (35-51)
3 or more	19 ± 6	0.5 (0.2-1.2)	0.2 (0.1-0.5)	4 (2-9)
Tackle height[c]				
Head/neck	4 ± 2	4.3 (2.3-7.9)	0.4 (0.2-0.8)	13 (7-23)
High	37 ± 10	1.2 (0.8-1.7)	1.1 (0.8-1.6)	36 (26-47)
Middle	44 ± 9	0.9 (0.6-1.3)	1.0 (0.7-1.5)	32 (23-43)
Low	15 ± 5	1.6 (0.9-2.6)	0.6 (0.3-1.0)	19 (12-29)
Tackle direction[c]				
Front	59 ± 14	1.0 (0.7-1.4)	1.5 (1.1-2.1)	49 (38-60)
Side	35 ± 8	1.4 (1.0-2.0)	1.3 (0.9-1.8)	42 (31-53)
Behind	5 ± 3	2.2 (1.1-4.6)	0.3 (0.1-0.6)	9 (4-18)
Carrier motion[c]				
Stationary	6 ± 3	1.2 (0.5-3.1)	0.2 (0.1-0.5)	6 (2-14)
Walk	17 ± 6	0.8 (0.4-1.6)	0.4 (0.2-0.7)	11 (6-21)
Jog	48 ± 11	1.0 (0.7-1.5)	1.3 (0.9-1.8)	42 (31-53)
Run	24 ± 7	1.3 (0.9-2.1)	0.8 (0.5-1.3)	26 (18-37)
Sprint	4 ± 3	4.5 (2.5-8.1)	0.5 (0.3-0.9)	15 (9-25)
Tackler motion[c]				
Stationary	8 ± 5	0.8 (0.3-2.2)	0.2 (0.1-0.5)	6 (2-15)
Walk	30 ± 9	0.5 (0.2-0.9)	0.4 (0.2-0.7)	11 (6-22)
Jog	43 ± 9	1.1 (0.8-1.6)	1.2 (0.8-1.7)	39 (28-56)
Run	14 ± 5	2.4 (1.6-3.7)	0.9 (0.6-1.3)	28 (18-43)
Sprint	4 ± 2	5.0 (2.8-9.0)	0.5 (0.3-0.8)	16 (9-28)

[a]Data are mean (90% confidence intervals).
[b]Based on 87 494 tackle events; 100 injury replacements in 434 matches.
[c]Based on 43 366 tackle events; 53 injury replacements in 434 matches.

linear models. The differences in CIs were minimal, so we opted for generalized linear models because they required much less computing time.

We expressed uncertainty in the true (infinite-sample) values of statistics as 90% CIs.[29] We compared replacement injury rates by deriving rate ratios and their CIs with Proc Genmod, but for better assessment of magnitude of effects, we also calculated percentage differences in injury rates, as follows: CIs for the injury rate at each level were first converted to standard errors, assuming that the sampling distribution of the rates was normal. Confidence intervals for the differences between the percentage injury rates were then approximated by using partial differentiation to combine the errors for each level into a standard error for the percentage difference: if r_i = the rate of injury per 1000 player-hours for level i, for example, middle, of a tackle characteristic, for example, height; if e_i = the standard error for r_i; and if p_i = the percentage (%) of injuries due to level i = 100 $r_i / \Sigma r_i$, then the standard error for $p_1 – p_2 = 100\ \Sigma\ \{[\partial\ (p_1–p_2)/\partial r_i]\ e_i\}^2$. Confidence intervals for injury burdens were estimated using log transformation to combine factor uncertainty in injury rate with factor uncertainty in days off as independent errors.

We made inferences about true effects by declaring effects clear and interpreting their magnitude if the 90% CI did not include values that were greater than the least clinically important effect in both a positive and negative sense.[3] We assumed the following values of least clinically important effects: for difference in percentages of injury rates per 1000 player-hours, ±10%; for injury rate ratio and injury burden per 1000 tackles or tackle events, ×/÷ 1.10; and for injury severity, Cohen's standardized thresholds of 0.20,[3] representing 0.20 of the standard deviation (SD) in days off expressed as a factor (the factor SD raised to the power of 0.20).

To simplify the large number of comparisons of injury burden, we derived the mean factor CI for pair-wise comparisons of levels of a tackle characteristic and divided it by the smallest factor effect (1.1) to give the smallest ratio in the levels that could be interpreted as a clear outcome. The resulting clear outcomes were ratios in excess of ×/÷ 2.5 for ball carriers and ×/÷ 2.6 for tacklers.

RESULTS

Number of Tackles, Tackle Events, and Injuries

The 140 269 coded tackles represented 293 ± 46 (mean ± SD) successful tackles and 30 ± 8 missed tackles per

TABLE 2
Statistics for Medical Injuries to Ball Carriers Arising From Tackle Events and Resulting in Days Unavailable for Match Selection (New Zealand Players Only)

	No. of Injuries	Days Off, Mean ± SD	Injury Rate per 1000		Injury Burden (Days Off) per 1000	
			Tackle Events[a]	Player-Hours[a]	Tackle Events[a]	Player-Hours[a]
Total	152	35 ± 98	2.9 (2.5-3.3)	15 (13-17)	100 (71-150)	530 (370-760)
Number of tacklers						
1	81	41 ± 118	3.2 (2.6-3.8)	8.1 (6.7-9.7)	130 (79-210)	330 (200-540)
2	62	31 ± 71	2.8 (2.3-3.5)	6.2 (5.0-7.6)	88 (54-140)	190 (120-310)
3 or more	9	14 ± 21	1.9 (1.1-3.3)	0.9 (0.5-1.6)	27 (11-67)	13 (5-31)
Tackle height[b]						
Head/neck	8	23 ± 25	8.5 (4.7-15)	0.8 (0.4-1.4)	190 (89-410)	18 (8.4-39)
High	33	40 ± 71	3.4 (2.6-4.5)	3.3 (2.5-4.4)	140 (80-230)	130 (77-220)
Middle	32	52 ± 173	2.9 (2.1-3.8)	3.2 (2.4-4.3)	150 (64-340)	160 (72-380)
Low	8	21 ± 36	2.1 (1.2-3.8)	0.8 (0.4-1.4)	45 (17-120)	17 (6.4-45)
Tackle direction[b]						
Front	43	29 ± 55	2.8 (2.2-3.6)	4.3 (3.3-5.5)	82 (51-130)	130 (78-200)
Side	33	53 ± 173	3.7 (2.8-4.9)	3.3 (2.5-4.4)	200 (88-440)	180 (79-390)
Behind	5	59 ± 61	3.8 (1.8-7.9)	0.5 (0.2-1.0)	220 (89-560)	29 (12-74)
Carrier speed[c]						
Stationary	4	8 ± 4	1.6 (0.7-3.7)	0.4 (0.2-0.9)	13 (6.2-28)	3.2 (1.5-6.8)
Walk	29	46 ± 91	2.5 (1.9-3.4)	2.9 (2.1-3.9)	120 (63-210)	130 (72-240)
Jog	68	38 ± 125	2.6 (2.1-3.2)	6.8 (5.5-8.3)	97 (54-180)	250 (140-460)
Run	40	29 ± 60	3.7 (2.9-4.9)	4.0 (3.1-5.2)	110 (63-180)	120 (68-200)
Sprint	11	29 ± 34	8.5 (5.2-14)	1.1 (0.7-1.8)	240 (120-480)	31 (16-62)
Tackler speed[b]						
Stationary	3	110 ± 86	1.5 (0.6-3.9)	0.3 (0.1-0.8)	160 (57-470)	33 (11-94)
Walk	11	18 ± 24	1.4 (0.9-2.3)	1.1 (0.7-1.8)	26 (12-53)	20 (9.5-41)
Jog	41	43 ± 154	3.7 (2.8-4.8)	4.1 (3.2-5.3)	160 (71-350)	170 (79-380)
Run	19	41 ± 79	5.1 (3.5-7.4)	1.9 (1.3-2.8)	210 (100-430)	77 (38-160)
Sprint	7	36 ± 41	7.4 (4.0-14)	0.7 (0.4-1.3)	270 (120-620)	25 (11-58)

[a]Data are mean (90% confidence intervals).
[b]Based on 81 injuries from 25 587 tackle events with a single tackler only in 10 050 player-hours.
[c]Based on 152 injuries from 52 248 tackle events in 10 050 player-hours.

match. The tackles were associated with 87 494 tackle events, of which 49%, 42%, and 9% involved 1, 2, or more than 2 tacklers, respectively. There were 613 nonreplacement injury assessments and 100 replacement injuries to ball carriers. Injury assessments to ball carriers occurred at the rate of 7.0 per 1000 tackle events (35 per 1000 player-hours). The rate of ball carrier replacement was 1.1 per 1000 tackle events (5.8 per 1000 player-hours). There were 735 injury assessments to tacklers and a further 111 injury replacements. Injury assessments to tacklers occurred at the rate of 5.2 per 1000 tackles (42 per 1000 player-hours). The rate of tackler replacements was 0.8 per 1000 tackles (6.4 per 1000 player-hours).

Tackle Event Characteristics and Ball Carrier Injuries

In the following sections, the rates for given levels of a tackle characteristic are presented in the tables, and comparisons between levels (rate ratios and/or percentage differences in percentages) are presented in the text. Table 1 shows the effect of tackle-event characteristics on injury replacement rates for ball carriers. Table 2 shows the burden of injuries to New Zealand ball carriers, which were matched to assessment and replacement events in the video recordings. Carriers were replaced at a higher rate per 1000 tackle events when there was 1 tackler (rate ratio = 2.4; 90% CI: 1.0-5.5) or 2 tacklers (rate ratio = 2.3; 90% CI: 1.0-5.4) than when the event involved 3 or more tacklers. Carriers also had a higher rate of replacement per 1000 player-hours when tackled by 1 (rate ratio = 13; 90% CI: 5.7-31; percentage difference = 49%; 90% CI: 39%-59%) or 2 tacklers (rate ratio = 11; 90% CI: 4.6-25; percentage difference = 39%; 90% CI: 29%-49%) than when tackled by 3 or more. The differences between injury rates in tackle events with 1 tackler and those with 2 tacklers were unclear.

Tackles to the head/neck region resulted in replacement injuries to ball carriers at a higher rate per 1000 tackle events than low (rate ratio = 2.7; 90% CI: 1.2 to 6.1), middle (rate ratio = 4.8; 90% CI: 2.3 to 10), or high (rate ratio = 3.7; 90% CI: 1.8 to 7.6) tackle events. A different pattern was apparent when carrier replacement rate was modeled per 1000 player-hours: high tackles resulted in carrier

TABLE 3
Effect of Tackle Characteristics on Tackler Injuries[a]

	Tackles per Match, Mean ± SD	Replacement Rate per 1000 … Tackles	Player-Hours	Player-Hours as a Percentage, %
Total[b]	323 ± 50	0.8 (0.7-0.9)	6.4 (5.5-7.5)	100
Number of tacklers				
1	99 ±17	1.1 (0.8-1.4)	2.7 (2.1-3.4)	41 (34-49)
2	168 ± 32	0.6 (0.5-0.8)	2.7 (2.1-3.4)	41 (34-49)
3 or more	55 ± 19	0.8 (0.5-1.2)	1.1 (0.8-1.6)	17 (12-24)
Tackle height				
Head/neck	11 ± 5	0.6 (0.2-1.6)	0.2 (0.1-0.5)	3 (1-7)
High	151 ± 29	0.7 (0.5-0.8)	2.5 (1.9-3.2)	39 (30-50)
Middle	131 ± 2	0.7 (0.6-1.0)	2.4 (1.9-3.1)	38 (29-49)
Low	30 ± 10	1.8 (1.3-2.5)	1.3 (0.9-1.9)	21 (15-29)
Tackle direction				
Front	206 ± 39	0.7 (0.5-0.8)	3.4 (2.7-4.2)	53 (45-61)
Side	105 ± 20	0.9 (0.7-1.2)	2.4 (1.8-3.1)	37 (30-45)
Behind	11 ± 4	2.2 (1.3-3.6)	0.6 (0.4-1.0)	10 (6-16)
Carrier motion				
Stationary	14 ± 5	0.5 (0.2-1.3)	0.2 (0.1-0.5)	3 (1-7)
Walk	75 ±19	0.5 (0.3-0.7)	0.9 (0.6-1.4)	14 (10-21)
Jog	165 ± 32	0.7 (0.6-0.9)	2.9 (2.3-3.6)	45 (37-53)
Run	63 ± 16	1.3 (1.0-1.7)	2.0 (1.5-2.7)	32 (25-39)
Sprint	7 ± 4	2.5 (1.3-4.7)	0.4 (0.2-0.8)	6 (3-11)
Tackler motion				
Stationary	28 ± 13	0.4 (0.2-0.9)	0.3 (0.1-0.6)	5 (2-9)
Walk	118 ± 27	0.5 (0.3-0.7)	1.4 (1.0-1.9)	22 (16-29)
Jog	143 ± 29	0.8 (0.6-1.0)	2.8 (2.2-3.6)	44 (37-52)
Run	29 ± 8	1.9 (1.4-2.7)	1.4 (1.0-1.9)	22 (16-29)
Sprint	5 ± 3	4.0 (2.3-6.9)	0.5 (0.3-0.9)	8 (5-14)

[a]Data are mean (90% confidence intervals).
[b]Based on 140 269 tackles, 735 injury assessments (resumed play), and 111 injury replacements in 434 matches.

replacement more frequently than head/neck (rate ratio = 2.6; 90% CI: 1.3 to 5.4; percentage difference = 22%; 90% CI: 6% to 38%) and low (rate ratio = 1.9; 90% CI: 1.0 to 3.6; percentage difference = 17%; 90% CI: 0.1% to 34%) tackles. Middle tackles also resulted in replacement more frequently than head/neck (rate ratio = 2.3; 90% CI: 1.1 to 4.9; percentage difference = 18%; 90% CI: 2.6% to 34%) and low tackles (rate ratio = 1.7; 90% CI: 0.9 to 3.3; percentage difference = 13%; 90% CI: –3.2% to 29%).

Tackles from behind resulted in a higher rate of replacement to carriers per 1000 tackle events than did tackles from the front (rate ratio = 2.2; 90% CI: 1.0-4.9) or the side (rate ratio = 1.5; 90% CI: 0.7-3.5). The opposite profile was apparent with respect to rate of carrier replacement by direction per 1000 player-hours: tackles from the front (rate ratio = 5.1; 90% CI: 2.3-11; percentage difference = 39%; 90% CI: 29%-49%) and the side (rate ratio = 4.3; 90% CI: 1.9-9.8; percentage difference = 32%; 90% CI: 23%-41%) were more likely to result in replacement than tackles from behind.

Carriers were replaced at a higher rate per 1000 tackle events when they were sprinting than when moving at lower speeds; rate ratios ranged from 3.4 (90% CI: 1.7-7.1) for running to 5.5 (90% CI: 2.3-13) for walking. There was a different pattern of replacements per 1000 player-hours: the rate was highest when the carrier was jogging and lowest when stationary (rate ratio = 7.3; 90% CI: 2.6-20; percentage difference = 36%; 90% CI: 27%-44%). The effects of tackler motion on injury rates were very similar to those of carrier motion.

Tackle Characteristics and Tackler Injuries

Table 3 shows the effect of tackle characteristics on injury replacement rates for tacklers.

Table 4 shows the burden of injuries to New Zealand tacklers that were matched to assessment and replacement events in the video recordings. The replacement rate per 1000 tackles was higher for tackles with a single tackler than for tackles with 2 tacklers (rate ratio = 1.7; 90% CI: 1.2-2.4). Injury rates per 1000 player-hours were higher for single and double tackles than for tackles involving 3 or more tacklers (rate ratio = 2.4; 90% CI: 1.6-3.8; percentage difference = 24%; 90% CI: 13%-36%).

Tacklers making low tackles were replaced at a higher rate per 1000 tackles than those making high (rate ratio = 2.7; 90% CI: 1.8-4.1) or middle (rate ratio = 2.4; 90% CI: 1.6-3.7) tackles. A different pattern emerged for tackler replacements per 1000 player-hours: the highest rate was for high tackles and the lowest was for the head/neck region (rate ratio = 14; 90% CI: 5.4-38; percentage difference = 36%; 90%

TABLE 4
Statistics for Medical Injuries to Tacklers Resulting in Days Unavailable for Match Selection (New Zealand Players Only)

			Injury Rate per 1000		Injury Burden (Days Off) per 1000 …	
	No. of Injuries	Days Off, Mean ± SD	Tackles	Player-Hours[a]	Tackles	Player-Hours[a]
Total[b]	129	26 ± 78	1.5 (1.3-1.8)	13 (11-15)	40 (26-60)	330 (220-500)
Number of tacklers						
1	56	41 ± 104	2.2 (1.8-2.7)	5.6 (4.5-6.9)	89 (52-150)	230 (130-390)
2	45	20 ± 60	1.0 (0.8-1.3)	4.5 (3.5-5.7)	21 (11-41)	90 (46-180)
3 or more	28	8 ±15	1.8 (1.3-2.5)	2.8 (2.0-3.8)	15 (8-28)	23 (13-43)
Tackle height						
Head/neck	3	14 ± 15	1.0 (0.4-2.7)	0.3 (0.1-0.8)	14 (3.8-52)	4.1 (1.1-15)
High	45	29 ± 92	1.1 (0.9-1.4)	4.5 (3.5-5.7)	33 (16-65)	130 (65-260)
Middle	64	25 ± 77	1.9 (1.5-2.3)	6.4 (5.2-7.8)	47 (27-84)	160 (91-290)
Low	17	26 ± 49	2.2 (1.5-3.3)	1.7 (1.1-2.5)	59 (28-120)	45 (22-93)
Tackle direction						
Front	77	24 ± 74	1.4 (1.2-1.7)	7.7 (6.3-9.2)	34 (20-58)	180 (110-310)
Side	43	19 ± 71	1.6 (1.2-2)	4.3 (3.3-5.5)	30 (14-66)	82 (38-180)
Behind	9	82 ± 127	3.1 (1.8-5.4)	0.9 (0.5-1.6)	260 (110-620)	74 (31-180)
Carrier speed						
Stationary	6	4 ± 4	1.6 (0.8-3.2)	0.6 (0.3-1.2)	6.5 (2.9-14)	2.4 (1.1-5.3)
Walk	15	80 ± 187	0.7 (0.5-1.1)	1.5 (1.0-2.3)	59 (24-150)	120 (48-300)
Jog	71	13 ± 29	1.6 (1.4-2)	7.1 (5.-8.6)	22 (14-34)	95 (62-140)
Run	29	19 ± 26	1.8 (1.3-2.5)	2.9 (2.1-3.9)	35 (22-56)	55 (34-88)
Sprint	8	85 ± 135	5.0 (2.8-9.0)	0.8 (0.4-1.4)	430 (170-1100)	68 (26-180)
Tackler speed						
Stationary	6	9 ± 8	0.9 (0.4-1.7)	0.6 (0.3-1.2)	8.1 (3.6-18)	5.6 (2.5-12)
Walk	37	17 ± 35	1.2 (0.9-1.5)	3.7 (2.8-4.8)	20 (11-34)	61 (35-110)
Jog	57	20 ± 81	1.5 (1.2-1.9)	5.7 (4.6-7.1)	31 (15-64)	120 (55-240)
Run	22	39 ± 98	3.0 (2.1-4.2)	2.2 (1.5-3.1)	120 (52-260)	85 (38-190)
Sprint	7	103 ± 139	5.3 (2.9-10)	0.7 (0.4-1.3)	550 (220-1400)	72 (29-180)

[a]Data are mean (90% confidence intervals).
[b]Based on 129 injuries from 84 755 tackles in 10 050 player-hours.

CI: 27%-45%), while low tackles had an intermediate rate; replacement rate for middle tackles was similar to that for high, but the difference was unclear.

Tackles from behind (rate ratio = 2.0; 90% CI: 1.0-4.1) and from the side (rate ratio = 1.6; 90% CI: 1.2-2.3) resulted in a higher rate of replacement per 1000 tackles than tackles from the front, whereas replacements per 1000 player-hours were much more frequent for front-on (rate ratio = 5.4; 90% CI: 3.1-9.2; percentage difference = 43%; 90% CI: 33%-54%) or side-on (rate ratio = 3.7; 90% CI: 2.1-6.5; percentage difference = 27%; 90% CI: 17%-37%) tackles than tackles from behind.

Tacklers were replaced at a higher rate per 1000 tackle events when carriers were sprinting than when moving at lower speeds: rate ratios ranged from 2.0 (90% CI: 1.0-3.9) for running to 5.1 (90% CI: 2.4-11) for walking. Tacklers were also at higher risk when they were sprinting: rate ratios varied from 2.1 (90% CI: 1.1-4.0) compared with running through to 9.8 (90% CI: 3.9-25) compared with stationary. There was a different pattern of replacements per 1000 player-hours: the rate was highest when jogging and lowest when stationary for carrier movement (rate ratio = 17; 90% CI: 6.3-44; percentage difference = 42%; 90% CI: 34%-51%) and tackler movement (rate ratio = 9.8; 90% CI: 4.5-21; percentage difference = 40%; 90% CI: 30%-49%). Tackles in which a single tackler was involved also resulted in higher injury burdens to tacklers per 1000 tackles and per 1000 player-hours than tackles in which multiple tacklers were involved.

Effect of Playing Position

The effects of player position on numbers of tackle events, tackles, and replacement injuries are shown in Figures 2 and 3. Backs were replaced at about twice the rate as forwards per 1000 tackle event when they were ball carriers (rate ratio = 2.0; 90% CI: 1.4-3.3) and per 1000 tackles when making tackles (rate ratio = 1.7; 90% CI: 1.3-2.5).

Inciting Events

There were 281 medical injuries to New Zealand players matched to video records via the RugbyMed database, of which 152 were injuries to ball carriers and 129 were injuries to tacklers. In the results to follow, the percentages presented are the percentage of injuries caused by a given

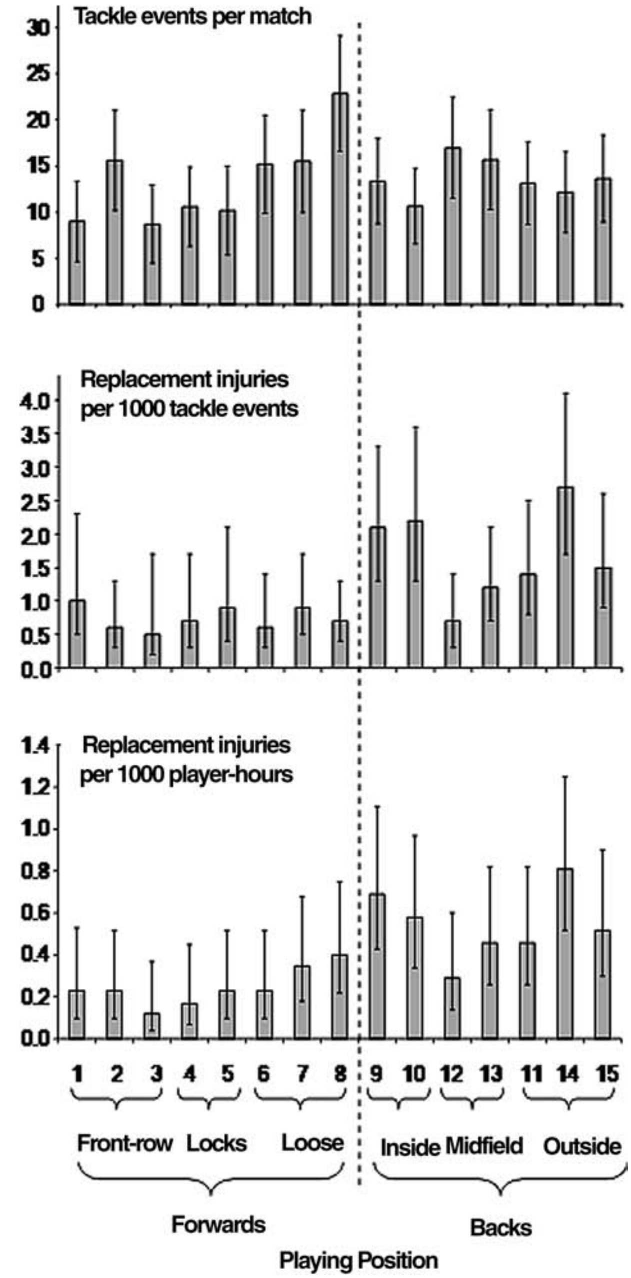

Figure 2. Tackle event and injury rates for ball carriers by position.

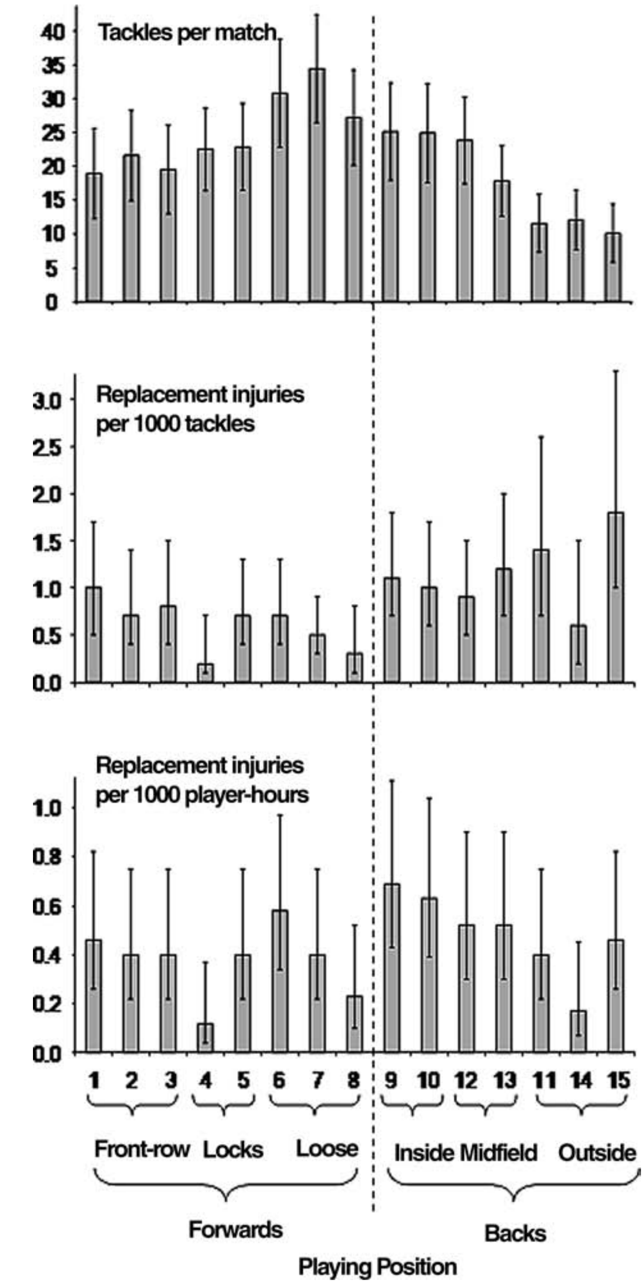

Figure 3. Tackle and injury rates for tacklers by position.

inciting event, along with the 90% CI of the percentage. The injuries to ball carriers arose from impact between players (45%; 90% CI: 39%-52%), tackler(s) loading the ball carrier's body with their weight (29%; 90% CI: 24%-36%), and the ball carrier falling/impacting the ground (19%; 90% CI: 15%-25%); 7% (90% CI: 5%-12%) were unable to be determined. There were 39 ball-carrier injuries to the head/neck region, of which 29 were to the head and face. The most common inciting event for injuries to the head/neck was impact between players, of which 7 of 25 (28%; 90% CI: 17%-46%) were the result of impact between the carrier's head and tackler's head—all of which caused injuries to the head/face. A further 41 injuries to ball carriers were reported to the upper body; 49% (90% CI: 37%-62%) of these were to the shoulder/clavicle. There were 72 ball carrier injuries to the lower body, of which 33% (90% CI: 25%-43%) were to the knee, 31% (90% CI: 23%-41%) were to the ankle, and 14% (90% CI: 9%-22%) were to the lower leg/Achilles tendon. Loading of the ball carrier's body by the tackler(s) was the most common inciting event for lower limb injuries to ball

TABLE 5
Injury Severity (Days Off) and Injury Burden (Days Off per 1000 Player-Hours) for Injuries to Different Body Regions Arising From Different Inciting Events for Ball Carriers and Tacklers (New Zealand Players Only)

Body Region	Inciting Event	No. of Events	Days Off, Mean ± SD	Injury Burden (Days Off) per 1000 Player-Hours[a]
Ball carrier				
Head/neck	Falling/hitting ground	8	6 ± 6	5 (2.3-11)
	Impact between players	25	19 ± 51	47 (21-110)
	Loading	1	0	–
	Uncertain	5	6 ± 7	3.1 (1.1-8.8)
Upper body	Falling/hitting ground	8	13 ± 20	10 (3.7-27)
	Impact between players	19	30 ± 45	56 (30-110)
	Loading	11	74 ± 95	81 (38-170)
	Uncertain	3	20 ± 26	6 (1.3-27)
Lower body	Falling/hitting ground	13	12 ± 19	16 (7.6-34)
	Impact between players	24	19 ± 52	46 (20-100)
	Loading	32	83 ± 190	260 (140-500)
	Uncertain	3	3 ± 3	0.80 (0.22-2.8)
Total		152	35 ± 98	530 (370-760)
Tackler				
Head/neck	Falling/hitting ground	2	0	–
	Impact between players	53	8 ± 9	42 (30-58)
	Loading	1	14	–
	Uncertain	5	7 ± 5	3.2 (1.3-7.8)
Upper body	Falling/hitting ground	8	27 ± 59	22 (6.7-71)
	Impact between players	19	26 ± 52	49 (23-100)
	Loading	1	81	–
	Uncertain	4	12 ± 14	4.9 (1.5-16)
Lower body	Falling/hitting ground	5	42 ± 34	21 (8.3-52)
	Impact between players	17	53 ± 94	89 (43-190)
	Loading	9	80 ± 200	72 (21-240)
	Uncertain	5	44 ± 28	22 (9.4-52)
Total		129	26 ± 78	330 (220-500)

[a]Data are mean (90% confidence intervals).

carriers (32 injuries of 72 [44%]; 90% CI: 36%-55%). Of the loading injuries, 38% (90% CI: 26%-53%) were to the ankle, 28% (90% CI: 18%-44%) were to the knee, and 22% (90% CI: 13%-37%) were to the lower leg/Achilles tendon region. A breakdown of body region injured by inciting event for ball carriers and tacklers is shown in Table 5.

The tackler injuries resulted from impact between players (69%; 90% CI: 63%-75%), the carrier loading the tackler's body (9%; 90% CI: 6%-13%), and the tackler falling/impacting the ground (12%; 90% CI: 8%-17%); 11% (90% CI: 8%-16%) were unable to be determined. There were 61 tackler injuries to the head/neck, of which 47 (77%; 90% CI: 68%-85%) were to the head/face. Of the 53 tackler injuries to the head/neck resulting from impacts between players, 28% (90% CI: 20%-40%) occurred through a collision between the tackler's head and the ball carrier's head, 23% (90% CI: 15%-34%) were the result of the tackler's head hitting the ball carrier's body, and in 17% (90% CI: 10%-28%) of cases the tackler's head collided with the head of another tackler. Impacts were also the most common inciting event for tackler injuries to the lower limb, accounting for 47% (90% CI: 35%-61%) of the 36 injuries. A further quarter of lower limb injuries to tacklers (25%; 90% CI: 16%-39%) were the result of loading of the tackler with the weight of the carrier during the tackle.

Ball carriers (47%; 90% CI: 41%-54%) sustained a greater percentage of injuries to the lower limb than did tacklers (28%; 90% CI: 22%-35%). The inciting event that resulted in the greatest injury burden (days unavailable per 1000 player-hours; 90% CI) for ball carriers was loading of the body (340; 90% CI: 200-580), followed by impact between players (150; 90% CI: 95-230). For tacklers, impact (190; 90% CI: 120-290) was the inciting event resulting in the greatest burden, followed by loading (88; 90% CI: 30-250).

DISCUSSION

Injury Risk Factors, Inciting Events and Injury Burden in Rugby Tackles

Injuries can be conceptualized as resulting from a transfer of energy that exceeds the ability of the body to maintain its structural or functional integrity.[14] Whether a particular rugby tackle results in injury depends on the amount of energy transferred, the size of the area over which the force is distributed, the direction(s) of the forces, and the biomechanical properties of the body structures to which the energy is transferred.

In general, the most common types of tackles and tackle events resulted in the most injuries and highest injury burden per 1000 player-hours. Thus, ball carriers were most frequently replaced after receiving high or middle tackles to the front or side, and tacklers were most often replaced after high or middle tackles made to the front or side of the ball carrier. Certain types of tackles that resulted in injury at relatively high rates per event occurred at low frequencies in the sport, which meant that they did not contribute substantially to the overall morbidity related to the tackle situation; examples are the injuries associated with the movement speed of either ball carriers or tacklers. Per occurrence, tackles in which players were sprinting resulted in injuries at 3 to 5 times the rate of injury of tackles in which players were moving at lower speeds. The average days missed per injury from tackles in which players were sprinting were also higher than for those in which players were moving at lower speeds. The relative rarity of tackles in which players were sprinting, however, meant that they accounted for a much lower proportion of injuries overall than tackles in which players (either the ball carrier or the tackler) were jogging. The injury burden per 1000 hours of play was also higher for tackles in which players were jogging than when they were sprinting, especially for ball carriers.

A previous study of rugby injuries noted similar differences in the distribution of injuries between tacklers and ball carriers.[13] Given that the direction and points of application of energy differ between the tackler and ball carrier, it is not surprising that there are differences between tacklers and ball carriers in the distribution of injuries across the body and the proportion of injuries resulting from the various types of inciting events.

Injury Prevention Opportunities

From an injury prevention perspective, understanding the rates and time unavailable for selection as a result of injury, both per event and per unit of exposure time, is useful. As noted in a recent paper outlining risk management strategies in sport,[12] frequent injuries of moderate severity may carry the same overall injury burden to participants in a sport as rare but severe injuries. In addition, once risks in a sport have been estimated, decisions need to be made about whether the risks are acceptable or unacceptable to the stakeholders of the sport.[12] In either case, information about the risk should be communicated to the sports community, but where risks are deemed to be unacceptably high, injury prevention strategies need to be implemented.[12] The views of stakeholders (ie, fans, the medical community, administrators, and players) on whether a particular level of risk is acceptable may vary widely. Within rugby, if the overall level of injury from tackles was considered acceptable to stakeholders, then targeting those tackle circumstances that occur infrequently but carry disproportionately high rates and burdens of injury per event would be a logical area on which to focus injury-prevention efforts. This would result in the least disruption to the structure of the sport. On the other hand, if the overall frequency and costs of injury from tackles were deemed to be unacceptably high, then focusing injury-prevention efforts on those tackles that result in the greatest burden of injury per 1000 hours of play would be expected to bring about the greatest reduction in player morbidity. Because the tackles associated with the highest burden of injury per unit of player exposure are among the most common in the sport (height: high or middle; direction: front or side; carrier speed: jogging; tackler speed: jogging), substantial changes to these would result in major modifications to the constitution of the sport.

Changing the laws of the game is an important potential strategy for preventing tackle injuries in rugby union. There were examples of injuries to ball carriers where the initial impact from the tackler was below the shoulder line, that is, at legal height, but the direction of the tackler led to the tackler's shoulder impacting the head of the ball carrier, which resulted in injury. Calls to lower the height of the tackle line from the top of the shoulders to the axillae (armpits) have been made by previous researchers.[23,31] Subsequent to the submission of this paper for review, the IRB set out a change to the interpretation of the laws regarding dangerous tackles, which stated that a tackle which made contact with the ball carrier above the line of the shoulders was dangerous regardless of whether the head or neck was the point of the first or subsequent contact. Presumably, this change will reduce the risk of tackles that start at the level of the chest connecting with the head of the ball carrier, and lower the risk of head-to-head contact. Whether this change will modify the risk of injuries for tacklers is worth monitoring, as the risk per tackle for tacklers was similar for head/neck, high, and middle tackles, but higher for low tackles. If the change to the legal tackle height results in tacklers making a greater proportion of low tackles, they might sustain a greater number of injuries.

Educational initiatives that focus on technique, physical conditioning, and the wearing of protective equipment are another avenue for reducing injury in rugby.[26] The use of incorrect technique has been identified as a risk factor for tackle injuries among schoolboy players,[21] and injury prevention efforts in amateur New Zealand rugby have focused on the correct technique for ball carriers and tacklers to adopt when being tackled or tackling.[26] Even among professional players, however, we observed a number of instances in which poor technique was a contributing factor to the injury occurring. Dropping the chin forward into the contact appears to increase the risk of head/neck injury through hyperflexion of the cervical spine.[23] Head-to-head contacts, either between the tackler and the ball carrier or between 2 tacklers who concurrently tackled the ball carrier from either side, comprised a substantial proportion (40%) of inciting events to the head/neck in the current study. Education measures that focus on teaching players to keep their chins off their chests, their eyes open, and to be aware of the location of other players as they move into the tackle situation may help reduce the risk of this type of injury. In American football, tackles in which tacklers impacted the opponent with the top of the head (spear tackles) were banned because they carried a high risk of spinal injury to the tackler. In rugby there is no censure for tackles that put the tackler at risk of serious spinal injury.

On reviewing the inciting events for injuries, it was notable that a number of the more severe injuries to the lower limbs resulted from the loading of a player's body with the weight of an opponent. In instances where the tackler jumped on the ball carrier from the side or behind and the ball carrier attempted to continue running, the ball carrier appeared to be at particular risk of severe knee, lower leg, and ankle injuries. Tacklers were also at risk of injury via such tackles, especially when their legs became tangled with those of the ball carrier, although tacklers were injured less frequently than ball carriers from this mechanism. Reducing the risk of tackles such as these, which result in major consequences to the player and the team in terms of the player's ongoing participation, but are permitted within rugby, may require greater attention via education-based injury prevention than has been the case previously. For example, teaching ball carriers to go to ground immediately when they feel the weight of the tackler may be a means of reducing risk of injury to ball carriers. The trade-off for players and coaches is that of gaining a meter or two of field position from a particular run versus having a player unavailable through injury for an extended period.

The fact that backs had a higher rate of injuries than forwards is likely to be due in part to the typical movement speed of players (and subsequent impact forces) from various positions.[6] Backs made a greater proportion of their tackles while running or sprinting compared to forwards. The finding that higher movement speeds resulted in higher injury rates has implications for the lawmakers of rugby. Current proposals to change the laws of the game, including increasing the distance between the 2 backlines in an attempt to allow players greater time and space before reaching the tackle zone, will probably increase the risk of injury by increasing energy transfer between tackler and ball carrier (assuming the total number of tackles per match remains relatively constant).

Strengths and Limitations of the Study

The strengths of this prospective study include a large sample size, a long monitoring period, the coding of all tackles and tackle events in each match, and the matching of injury events on the field with medical records. We believe that one of the strengths of the collection of information from video records is that it typically yields more accurate information about the circumstances associated with the injury than is available from player recall of the event or direct observation of data collectors, for example, physicians on the sidelines of matches. When combined with medical information about the injuries, systematic video analysis provides a powerful approach to identifying risk factors for injuries in sport. By analyzing injury statistics with event and player-hour denominators, we have been able to draw inferences about the relative and absolute contribution to the injury rates and burden of the various kinds of tackles.[15] Our findings will help administrators, sports medicine specialists, and participants develop and implement targeted injury-prevention strategies.

A limitation was the fact that medical information regarding injury site, type, and severity was available only for those injuries occurring to New Zealand-based players. While it would have been ideal to have this information for all injuries, the subsample of New Zealand-based players was sufficiently large to allow useful inferences about inciting events and the corresponding burden of injury to be drawn. Many of the limitations associated with capturing data from video recordings have been outlined previously.[20] Specifically, not all injuries that occur during the matches can be seen on video, although the tackle situation is often better able to be examined than scrums, rucks, or mauls, which have bodies massed together. Likewise, not all on-field injury assessments result in a player seeking further medical attention following the match. The tackle situation is dynamic, and cases in which player actions are obscured can increase the likelihood of misclassification of categories; thus, much depends on the quality of match coverage. Injury events, especially those that resulted in the player being replaced or receiving extended medical attention on the field, were often replayed on multiple camera views, which assisted in the coding of the circumstances and inciting events of those tackles that resulted in injury.

CONCLUSION

The most common tackles in rugby are responsible for the greatest number of injuries, but certain types of tackle carry a higher degree of risk. Prevention of tackle injuries needs to balance the frequency and severity of injuries sustained with the desire of rugby participants (including players, administrators, and supporters) to maintain the full-contact nature of the sport.

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THESIS CHAPTER 6

CHANGES IN PLAYER CHARACTERISTICS AND MATCH ACTIVITIES IN BLEDISLOE CUP RUGBY UNION FROM 1972 TO 2004

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Changes in player characteristics and match activities in Bledisloe Cup rugby union from 1972 to 2004

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Abstract

To illustrate changes in elite rugby union match activities, we analysed coded videotape recordings of the first match in each Bledisloe Cup series played between Australia and New Zealand from 1972 to 2004. We also analysed the stature and body mass of players. Effects associated with professionalism, weather conditions, and time (expressed as change per decade) were estimated with a simple generalized linear model and standardized for interpretation of magnitude. The sample size permitted confident conclusions about effects that were of at least moderate magnitude (standardized mean difference >0.6). Increases in passes, tackles, rucks, tries, and ball-in-play time were associated with the advent of professionalism, whereas there were reductions in the numbers of lineouts, mauls, kicks in play, and in mean participation time per player. Noteworthy time trends were an increase in the number of rucks and a decrease in the number of scrums. Good weather conditions were associated with increases in tries and points scored and with reductions in the number of kicks in play and participation time per player. With the advent of professionalism, players have become heavier and backs have become taller. Overall, there have been major changes in international rugby match activities and player size over the past three decades. We believe law changes and developments in match analysis, equipment technology, and player training have contributed to the changes associated with the introduction of professionalism.

Keywords: *Rugby union, match activities, notational analysis, performance, player size, law changes*

Introduction

Rugby union football has been an international sport since 1871, when England and Scotland contested the first international match. Rugby became an openly professional sport in August 1995, a development that resulted in major changes to international competitions, governance, and player remuneration (Malcolm, Sheard, & Smith, 2004; Thomas, 2003).

The laws of rugby (International Rugby Board, 2005a) have changed more frequently than those of comparable sports (Noakes & Du Plessis, 1996; Royds, 1949; Stewart, 1997). There were several law amendments between 1972 and 1995 (S. Griffiths, Strategic Operations Manager, International Rugby Board, personal communication). The lineout was changed in 1982, with the introduction of a 1-m gap between the players in the two teams. More law changes were introduced in 1992, including an increase from four to five in the number of points awarded for a try, changes to the setting up and referee's control over scrums, and the entitlement of teams to replace four players (maximum) for injuries. In 1994, the "use it or lose it" law for mauls was brought in: when a team took the ball into a maul, was unable to release it, and the opposition halted the forward movement of the maul, the referee would call a scrum with the opposition team having the put-in.

Further law changes arose following the introduction of professionalism (S. Griffiths, personal communication). In 1996, the lineout was modified again, with the jumper being permitted "support" from other members of their team once they jumped for the ball. A law change allowing two extra reserves, meaning that four players could be replaced for injury from six reserves, was also introduced in 1996. The number of reserves changed again in 1997, with seven injury replacements permitted from seven reserves. Non-injury replacements were allowed for the first time, with two front row players and three other players eligible for substitution during matches at the prerogative of the coach. Red

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and yellow cards for misconduct first appeared in 2000. Players shown a red card by the referee were required to leave the field for the remainder of the match. A yellow card resulted in a 10-min suspension. A modification to the "use it or lose it" law in 2001 allowed the team in possession of the ball at a maul 5 s either to free the ball or restart forward movement of the ball prior to the referee calling a scrum. An experimental law variation that provided the ball to the opposition team if the scrum "wheeled" through more than a 90° angle also came into effect in 2001.

The Bledisloe Cup has been contested between the international rugby teams of Australia and New Zealand since the early 1930s. Bledisloe Cup matches were held irregularly until 1987. Since then the trophy has been contested annually, either as a single match or a series of matches. Since 1996, Bledisloe Cup matches have become part of the Tri-Nations series contested between Australia, New Zealand, and South Africa. Within this series teams are awarded four competition points if they win a match, two points if the match is drawn, and no points for a defeat. If a team scores four tries or more they are awarded a bonus point, and if they lose by seven points or less they are also awarded a bonus point.

Little work examining the changes to match activities in international rugby over the past three decades has been published. Both the International Rugby Board (2005b) and notational analysts (Potter & Carter, 1996) have produced descriptions of match activities in professional rugby tournaments, but these reports have not focussed on the evolution of match-play events. Stewart (1997) provided an historical analysis of changes to laws and qualitatively described subsequent patterns of activities. Eaves and Hughes (2003), in a study of Five and Six Nations matches covering the period 1988 – 2002, found that rugby became a faster, ruck-dominated game that contained more phases of play following the introduction of professionalism. The purpose of this study was to use a combination of notational analysis and historical records to illustrate changes in rugby match activities and the size of rugby players over a series of international matches that encompassed the change from an amateur to a professional sport. During the review of this article, two papers addressing similar issues have appeared (Eaves, Hughes, & Lamb, 2005; Williams, Hughes, & O'Donoghue, 2005).

Methods

With institutional ethics approval, we analysed New Zealand Rugby Union (NZRU) data from the first Bledisloe Cup match in each year the trophy was contested from 1972 to 2004. The data were obtained from coded videotape records of matches. The coding was undertaken by a commercial rugby match coding company (Verusco Ltd., Palmerston North; www.verusco.com). Twenty-six matches were coded for the current project. Of these, 17 matches were played before the introduction of openly professional competitions in August 1995 and 9 were played after the introduction of professional competitions. The 1995 match took place on 22 July and was included in the pre-professional era. The activities of players from both teams who were near the ball (i.e. observable on camera and involved in play) were coded throughout each match. The frequency and duration of several events within each match were coded. These included scrums, rucks, mauls, tackles, lineouts, passes, kicks, scores, penalties awarded, total match time, and time during which the ball was in play. The coding followed a detailed schema and there was a sensitive quality control process that ensured the events matched exactly what was observed on the video. Once coded, the event was linked to the video, which allowed verification of the coding. Each match took approximately 35 person-hours to code. To date there has been no systematic attempt to quantify miscoding because of the expense and the apparent fidelity between the coding and the video records. As well as counting the numbers of specific match activities, we qualitatively examined changes to the characteristics of scrums, lineouts, and tackles that were obvious from the video records.

The years in which law changes were introduced were obtained from IRB records (S. Griffiths, personal communication). Chester, Palenski, and McMillan (2000) and a New Zealand Rugby Union (2005) website (http://stats.allblacks.com) provided information on environmental conditions. Records of stature and body mass of New Zealand players prior to each match were obtained from the NZRU (2005). These records were not accurate assessments of the type used in anthropometric studies, but were provided to the NZRU by team personnel for inclusion in match programmes and almanacs.

Statistical analyses

All analyses were performed with the generalized linear modelling procedure (Proc Genmod) in SAS (Version 8.2, SAS Institute, Cary, NC). The main aim of the modelling was to estimate the effect of professionalism on the game and players, after adjusting (controlling) for long-term trends and for the effects of environmental conditions. Preliminary analyses showed that a main-effects model was adequate to characterize the data: nominal for era (with levels *pre-professional* and *professional*), numeric linear for year of the game, and nominal for ground conditions (*firm, soft*), rain (*no, yes*), and wind (*calm, windy*). A logarithmic link function provided estimates of effects as percentages. The response probability distribution was chosen according to the nature of the dependent variable: Poisson for frequencies, binomial for proportions, and normal for all other variables. A negative binomial parameter was included for the frequency variables to allow for greater residual variation in the variable than would be accounted for by the Poisson distribution. Proc Genmod did not permit specification of different residual variation in the two eras for any of the three response distributions, so we assumed this limitation would not seriously affect the estimates and their uncertainty.

To characterize the changes in the game since the introduction of professionalism, we have presented the values of each dependent variable predicted by the model for the final year of the pre-professional era (1995) and the final year for which data were available (2004), for a game performed in good conditions (firm ground; no rain; calm); we have also provided a measure of standard deviation in the variable derived from the standard deviation of the residuals (difference in the observed and predicted values) for the two eras. Effects of era, environmental conditions, and annual trend controlled for the other effects in the model are shown in separate tables as percentage differences (for era and conditions) and as percentage change over a decade (for annual trend). These effects were also standardized and expressed as magnitudes using a modified Cohen scale, where $<0.2=$ trivial, $0.2-0.6=$ small, $0.6-1.2=$ moderate, $1.2-2.0=$ large, and $>2.0=$ very large (Hopkins, 2003). The standard deviation used to standardize the effects was the square root of the mean of the variances of the residuals of the two eras, and the standardization was performed with the log-transformed variables. Only the qualitative magnitudes are shown in the tables.

In keeping with recent trends in inferential statistics (e.g. Petersen, Wilson, & Hopkins, 2004; Sterne & Davey Smith, 2001), we made magnitude-based inferences about true (population) values of effects by expressing the uncertainty in the effects as 90% confidence limits. An effect was deemed unclear if its confidence interval overlapped the thresholds for substantiveness (i.e. if the chances of the effect being substantially positive and negative were both $>5\%$); otherwise, the magnitude of the effect was reported as the magnitude of its observed value (Batterham & Hopkins, 2005).

Results and discussion

The results are grouped under the following headings: match exposure and participation (Tables I and II), scoring and penalties (Tables III and IV), match activities (Tables V and VI), and player size (Tables VII and VIII). Figure 1 presents the annual trends of selected variables.

The sample of matches was small, owing to constraints of cost and time. To reduce variation in the data, we restricted the analysis to the opening annual game between two traditional southern hemisphere rivals. Most of the effects of time and professionalism were at least moderate and were therefore clear, in spite of the limited sample size. Overall, the match activities and match time variables are consistent with previous reports that have examined international matches in the northern hemisphere (Eaves & Hughes, 2003; Eaves *et al.*, 2005) and the Rugby World Cup (Potter & Carter, 1996).

Previous researchers have remarked upon the match-to-match variability in match activities. Such variability can be observed in several of the graphs presented in Figure 1. Factors such as the referee, weather conditions, ground conditions, the tactics employed by the teams, and the time of the match (e.g. day vs. night matches) are believed to play a role

Table I. Measures of match participation under good conditions for 1995 (the last year prior to professionalism) and 2004 (predicted values ± standard deviation).

	1995	2004
Total match time (min)	83.7 ± 1.8	85.5 ± 3.6
Time ball in play (min)	28.6 ± 2.2	34.5 ± 1.8
Mean time per player (min)	79.4 ± 2.6	64.3 ± 3.5
Number of players	31.5 ± 1.2	40.1 ± 2.5

Table II. Effects on match participation (mean changes with 90% confidence limits; ↑, increase; ↓, decrease).

	Professionalism		10-year trend		Good conditions	
	Effect (%)	Magnitude	Effect (%)	Magnitude	Effect (%)	Magnitude
Total match duration (min)	4.3; ± 3.4	Large ↑	−2.3; ± 1.6	Moderate ↓	−0.1; ± 2.8	Unclear
Time ball in play (min)	18.9; ± 8.2	Very large ↑	1.6; ± 3.7	Unclear	−4.3; ± 5.2	Moderate ↓
Mean time per player (min)	−16.2; ± 3.7	Very large ↓	−3.7; ± 2.0	Moderate ↓	−7.0; ± 3.5	Large ↓
Number of players	23.8; ± 6.4	Very large ↑	3.2; ± 3.0	Moderate ↑	10.6; ± 4.8	Very large ↑

in this variability (Duthie, Pyne, & Hooper, 2003; James, Mellalieu, & Jones, 2005). Another source of variability in match activities that acts over longer periods arises from modifications to laws of the sport and changes in the interpretation or application of the laws that exist at a given time. As noted in the Introduction, law changes pertaining to specific aspects of the game were introduced over the period of the study – both before and after professionalism.

The current analyses allowed the changes in match activities associated with both long-term trends and the introduction of professionalism to be estimated while taking into account the effect of environmental conditions. We are unaware of any previous attempts to account for the nature of the variability in match activities while simultaneously controlling for these factors. Although we chose the introduction of professionalism as a convenient cut-off point for the purposes of illustrating changes to rugby matches and players over the period, we are not implying that the changes observed were caused solely by the introduction of professionalism. The changes in match activities and player characteristics observed are probably due to several factors, including law changes, developments in match analysis and tactics, modifications to player training, and equipment technology.

Match exposure and participation

From 1995 to 2004, there was an increase of approximately 20% in ball-in-play time (Tables I and II). Eaves and Hughes (2003) reported that ball-in-play time increased by a mean of 4 min and 45 s following the introduction of professionalism. We observed a similar pattern, with predicted ball-in-play time in good conditions increasing by 5 min and 54 s between 1995 and 2004.

The increase in ball-in-play time is related to the decrease in numbers of scrums and lineouts. Scrums are restarts in play after minor infringements, and lineouts are restarts when the ball travels over the sidelines. This increase in effective playing time has been offset to some extent for individual players through the introduction of three law changes to the sport: the ability to substitute players for tactical purposes in 1997, the "blood-bin" that allows players who have bleeding wounds to be temporarily replaced, and the introduction of red and yellow cards in 2000. As can be seen in Figure 1, there was a rapid decrease in mean time spent on the field per player following the introduction of substitutes, and there was a corresponding increase in the number of players taking part in each match (Table II). Analysis of the effect of environmental conditions indicates that teams make more substitutions in matches played in better conditions.

Scoring and penalties

The introduction of professionalism saw a large increase in tries scored and a moderate increase in points scored per match (Tables III and IV). Changes that could have influenced the willingness of teams to attempt to score tries rather than kick penalty goals included the increase in points for a try from four to five in 1992, and the development of bonus points in the Tri-Nations series (of which Bledisloe Cup matches now form a subset) for scoring four tries and, for the losing team, finishing within seven points of the victor (Torres & Hager, 2005). Although the overall accuracy of goal kickers has increased moderately over the series, the relationship between the introduction of professionalism and kicking accuracy was unclear in the current analysis.

Table III. Scoring attempts under good conditions for 1995 and 2004 (predicted values ± standard deviation).

	1995	2004
Points scored	39 ± 14	55 ± 23
Tries scored	3.5 ± 1.6	5.9 ± 3.9
Conversions	1.9 ± 1.2	3.0 ± 2.0
Penalties awarded	21.7 ± 4.4	22.6 ± 5.7
Penalties attempted	8.5 ± 2.6	8.1 ± 2.5
Penalties successful	5.4 ± 2.5	5.7 ± 2.5
Goals successful (%)	61 ± 25	63 ± 25

Table IV. Effects on points and penalty activities (mean changes with 90% confidence limits; ↑, increase; ↓, decrease).

	Professionalism		10-year trend		Good conditions	
	Effect (%)	Magnitude	Effect (%)	Magnitude	Effect (%)	Magnitude
Points scored	31; ± 40	Moderate ↑	9.1; ± 20	Unclear	62; ± 57	Large ↑
Tries scored	72; ± 104	Large ↑	−1; ± 32	Unclear	78; ± 100	Large ↑
Conversions	45; ± 125	Unclear	9; ± 48	Unclear	73; ± 144	Unclear
Penalties awarded	−1; ± 25	Unclear	5; ± 13	Unclear	−10; ± 19	Unclear
Penalties attempted	−10; ± 37	Unclear	6; ± 22	Unclear	30; ± 52	Unclear
Penalties successful	−8; ± 50	Unclear	17; ± 33	Unclear	11; ± 53	Unclear
Goals successful (%)	−8; ± 27	Unclear	13 ± 18	Moderate ↑	−16; ± 20	Moderate ↓

Favourable environmental conditions had a substantial positive effect on both the overall points scored and the number of tries scored per match. There was a moderate decrease in successful goal kicking in good conditions, which at first glance appears counter-intuitive. A possible explanation is that teams attempt slightly more difficult kicks in good conditions than in poor conditions.

Match activities

Scrums. In the current study, there was a moderate decrease in the number of scrums per match over time (Figure 1; Tables V and VI). The change to professionalism, however, was not associated with a significant change in the number of scrums. A recent paper examining frequencies of match activities (Eaves *et al.*, 2005) in international matches played in the northern hemisphere found a similar decrease in scrum frequency over time (from 1988–1992 to 2000–2002) but no significant effect for the change from the pre-professional to the professional era.

Players in the professional era spend more time in organized team practices, and the rewards available to those players who are able to obtain professional contracts mean that the development of skills receives greater focus than previously. While handling errors were not assessed in the current study, an increase in time spent in skills training, changes in ball construction, referees' willingness to "play advantage" after minor handling errors, and perhaps also pitch technology could have played a part in the decrease in scrums per match. Examination of historical match records indicates that leather balls were replaced by synthetic balls following the 1990 series, which were designed in part to be easier to grip.

Table V. Number of match activities under good conditions for 1995 and 2004 (predicted values ± standard deviation).

	1995	2004
Scrums	33 ± 7	26 ± 7
Lineouts	39 ± 6	28 ± 10
Rucks	72 ± 18	178 ± 27
Mauls	33 ± 8	22 ± 9
Passes	204 ± 30	247 ± 32
Kicks during play	66 ± 8	46 ± 13
Tackles	160 ± 32	270 ± 25

The decrease observed in the number of scrums per match has been accompanied by substantial changes in the body positions of players before and during the scrum. In early matches, the front rows stood more erect and set up further apart from each other than in matches later in the series. The engagement was controlled by the players, and often involved the front-row forwards taking an entire stride towards the opposition. The loose forwards would often join the scrum concurrent with or following the engagement of the two front rows in the 1972 and 1974 matches, whereas in matches in the 1980s and later the loose forwards were bound and in pushing positions before the engagement.

Ongoing changes to the nature of the scrum have been discussed by Stewart (1997), who reported the unintended consequences (Merton, 1936) of changes to laws in the early 1960s on changes to the dynamics of scrums and a subsequent increase in catastrophic spinal injuries. Because coaches and players seek a competitive advantage with respect to other teams and individual players, they tend to interpret and apply the laws in a manner that provides them with the maximum benefit. Thus law changes might or might not yield outcomes that were aligned with the intention of the law makers when the change was made. The law changes of the early 1960s that were designed to decrease the time-pressure that the scrum-half and fly-half were under following scrums, led to the development of so-called "power scrummaging". Power scrummaging occurs when the front rows of the two packs engage each other aggressively, and the ball is hooked slowly through the scrum with all eight members of the scrum actively engaged in a sustained drive.

In an attempt to reduce the risk of spinal injuries to front row players, changes to the laws controlling the scrum engagement were introduced in age-grade

Table VI. Effects on the number of match activities (mean changes with 90% confidence limits; ↑, increase; ↓, decrease).

	Professionalism		10-year trend		Good conditions	
	Effect (%)	Magnitude	Effect (%)	Magnitude	Effect (%)	Magnitude
Scrums	−8; ± 22	Unclear	−17; ± 10	Moderate ↓	−8; ± 19	Unclear
Lineouts	−14; ± 17	Moderate ↓	−19; ± 8	Moderate ↓	−6; ± 16	Unclear
Rucks	63; ± 33	Very large ↑	59; ± 18	Very large ↑	4; ± 17	Unclear
Mauls	−25; ± 21	Moderate ↓	−12; ± 12	Small ↓	1; ± 25	Unclear
Passes	20; ± 17	Large ↑	2; ± 8	Unclear	7; ± 13	Unclear
Kicks during play	−30; ± 14	Large ↓	0; ± 10	Unclear	−24; ± 13	Large ↓
Tackles	51; ± 23	Very large ↑	13; ± 9	Moderate ↑	4; ± 9	Unclear

rugby in the mid- to late 1980s, and internationally for all levels in 1992 (Carmody, Taylor, Parker, Coolican, & Cumming, 2005). The "crouch–touch–pause–engage" sequence was introduced to international rugby in early 1992 in an attempt to decrease the momentum of the two packs at engagement. The 'touch' command was subsequently dropped from international rugby, but has been reinstated as of January 2007.

Rucks and mauls. The number of rucks per match has increased almost four-fold since the introduction of professionalism. This marked increase in rucks is consistent with changes in the patterns of play observed by Eaves and Hughes (2003) and Eaves *et al.* (2005). The number of mauls per match has decreased during the same period, which also is in line with the patterns observed by Eaves *et al.* (2005). Both of these changes are likely to be related to the introduction of the use-it-or-lose-it law in 1994. This law increased the risk of losing possession in mauls and made the option of a ruck preferable to that of a maul for the team in possession of the ball. As can be seen in Figure 1, there was a rapid change in the style of play from 1994 onwards, in which players deliberately engaged the opponents' tackles to reduce the number of defenders available for the next move. The distribution of players around rucks has led to patterns of play in which both the attacking and defending team commit only a few of their players to each ruck, with the remainder spreading across the field in a defensive alignment in anticipation of the next move.

Anecdotally, it appears that the interpretation of laws as they apply to rucking for the ball have changed in southern hemisphere internationals, with less leniency shown by referees towards players who ruck or trample the bodies of opposing players lying on or near the ball.

Table VII. Player stature and mass (NZ players only) [predicted values ± standard deviation between games (not between players) for 1995 and 2004].

	1995	2004
Stature, forwards (cm)	190.5 ± 0.7	190.1 ± 1.0
Stature, backs (cm)	180.3 ± 1.1	182.9 ± 0.8
Mass, forwards (kg)	102.3 ± 1.2	111.1 ± 2.9
Mass, backs (kg)	83.4 ± 2.1	95.7 ± 2.3

Lineouts. There has been a reduction in lineouts per match over the study period (Figure 1; Tables V and VI). Whereas there were over 60 lineouts per match in 1972 and 1974, the predicted number in good conditions had dropped to 39 by 1995 and 28 by 2004. There was a 19% decrease per decade, and a 14% decrease associated with the introduction of professionalism.

The manner in which the ball is thrown in, and the position of the player throwing the ball in, has also changed. In the 1972 and 1974 matches, the ball was thrown into the lineout by the wings, with the left wing taking the throws on the left side of the field (as their team faced the opposition goal posts) and the right wing taking the throws on the right side of the field. Since then, almost all of the throws have been taken by the hooker. The video records illustrate that the type of throw has also changed, from a side-on, stiff-armed lob to a more front-on "spiral" throw.

Changes in the laws specifying the distance between the two forward packs as the lineout assembles were implemented in 1982. A change in the laws after the introduction of professionalism allowed players to be supported (lifted) as they jumped for the ball. From 1997 to 1999, teams often opted not to contest the opposition throw, but to prepare defensively on the assumption that the team throwing the ball would win it as of right. During these three years, the team throwing the ball won it almost always (Figure 1). From 2000 onwards, there has been an increase in the percentage of lineouts the non-throwing team contests, with a corresponding decrease in the percentage won by the team throwing the ball in.

Tackles. While the number of tackles per match was already showing an upward trend, there was a large increase following the introduction of professionalism (Figure 1; Tables V and VI). We believe that this increase was a further consequence of the use-it-or-lose-it law. As noted above, this law led to players deliberately taking the tackle. Analysis of the height

Table VIII. Effects on player stature and mass (NZ players only) (mean changes with 90% confidence limits; ↑, increase; ↓, decrease).

	Professionalism		10-year trend	
	Effect (%)	Magnitude	Effect (%)	Magnitude
Stature, forwards (cm)	−0.6; ± 0.5	Large ↓	0.5; ± 0.2	Large ↑
Stature, backs (cm)	1.1; ± 0.6	Very large ↑	0.5; ± 0.3	Moderate ↑
Mass, forwards (kg)	7.1; ± 2.1	Very large ↑	1.5; ± 1.0	Moderate ↑
Mass, backs (kg)	12.3; ± 3.0	Very large ↑	2.4; ± 1.5	Moderate↑

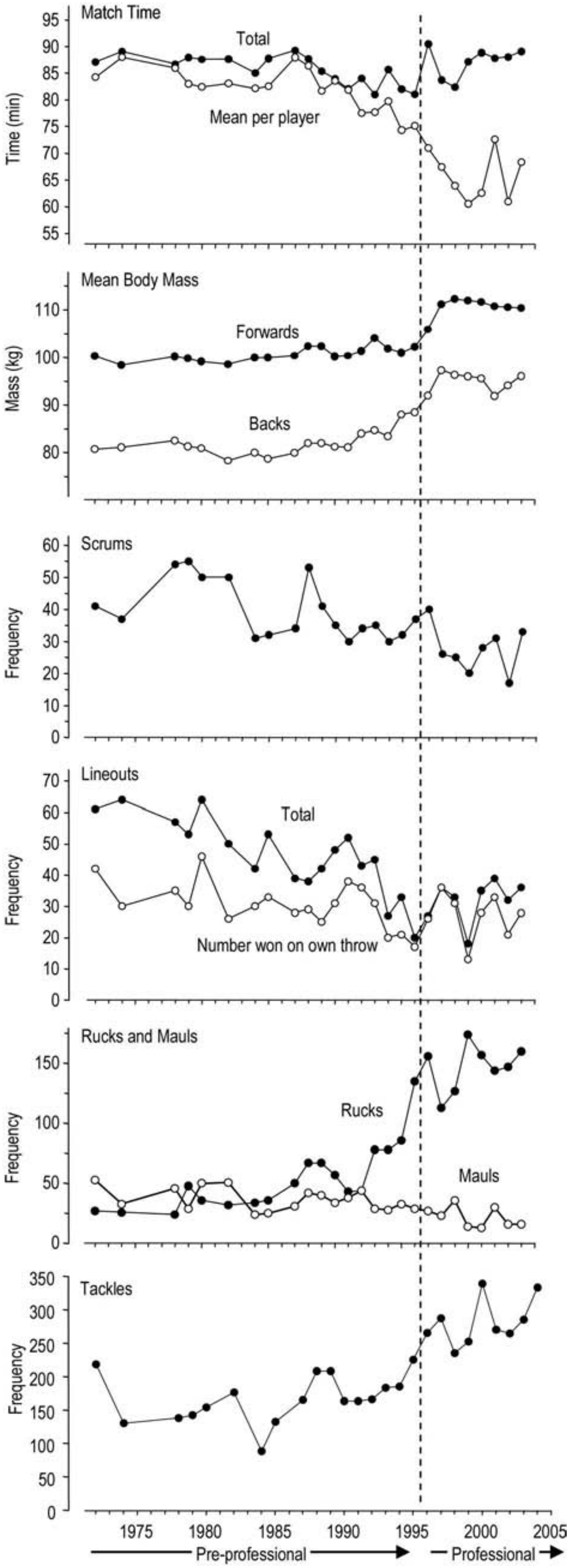

Figure 1. Match time, body mass (NZ players only), and match activities for the first Bledisloe Cup match of the years 1972–2004.

and direction of tackles showed little change in the relative proportions of each tackle type (data not shown). Tackles and rucks result in high-energy collisions between players, and hence place a large contact load on the body. Most of the injuries that occur in professional rugby are associated with these aspects of play (Bathgate, Best, Craig, & Jamieson, 2002; Brooks, Fuller, Kemp, & Reddin, 2005). There is evidence that there has been an increase in the rate of injuries in international rugby since the sport became professional (Bathgate *et al.*, 2002).

Kicks during play. Poor conditions were associated with 24% more kicks in play per match than matches played in good conditions over the series (Table VI). There was a large decrease (30%) in number of kicks in play per match following the introduction of professionalism. When controlling for the effect of professionalism, the decade trend for kicks during play appeared to be insubstantial, but a larger sample size would be required for confident assertions about the effect magnitude. These findings contrast with those of Eaves *et al.* (2005), who reported significant effects for both the change to professionalism and across four selected periods between 1988 and 2002. Their analysis, however, did not control for the effects of underlying trend on the change to professionalism.

Player size

Olds (2001) highlighted several limitations in anthropometric data drawn from public records, including tendencies to exaggerate and round measurements upward and changes in measurement techniques over time. Notwithstanding these limitations, the current data indicate that there was a rapid increase in player mass subsequent to the introduction of professionalism over and above the moderate increases in body mass occurring over time (Figure 1; Table VIII). Olds (2001), who documented changes in the size of rugby players in the twentieth century, reported that increases in the mass of male rugby players were more rapid than increases in the mass of males in the general population, with an acceleration in the pace of change from 1975 onward. The accelerated increase in body mass since 1975 that Olds (2001) reported appears to be due at least in part to the increase immediately following the introduction of professionalism that is apparent in our data.

Olds (2001) suggested that some sports can be considered Darwinian systems, with selection pressure for physiques that best match the requirements of the sport. Some of the changes observed in the current study lend support to this conception. Although the observation that the physiques of rugby players reflect the specific demands of the sport has been remarked upon previously (Noakes & Du Plessis, 1996; Olds, 2001; Quarrie, Handcock, Toomey, & Waller, 1996), the rapid increase in body mass observed subsequent to the introduction of professionalism was probably the result of selection pressure towards increased body mass. In 1997, non-injury substitutes were permitted for the first time, with the effect of decreasing mean time spent on the field per player. Less mean time on the field per player has probably facilitated the increase in mass due to a reduction in the relative aerobic requirements and an increase in the relative anaerobic requirements of the sport. At the same time, the flow-on effects from the use-it-or-lose-it law introduced in 1994 resulted in teams developing sequences of moves based on repeated rucks. There were, consequently, more rucks and tackles per match and a greater demand for players to repeatedly demonstrate power in the contact phases. Greater body mass confers an advantage in the contact phases of the sport, because of the greater momentum players are able to generate. An increased focus on weight training and attention to nutrition following the introduction of professionalism may also have assisted players to make these changes in body mass.

The stature of backs has also increased considerably since 1995. In addition, the backs are now involved more in plays such as rucks and mauls that were traditionally the domain of the forwards, and as predicted by Noakes and Du Plessis (1996), their physiques have tended towards what was the typical physique of loose forwards in the early to mid-1990s.

Professionalism was also associated with a decrease in the stature of forwards, although this was offset by a long-term increase in forwards' stature, and so there has been little change overall. This decrease was coincident with the introduction of the law permitting jumpers to be supported in the lineout. One explanation is that the absolute requirement for stature among lineout jumpers decreased somewhat at this time, because good lifters were able to overcome slight disadvantages in jumper stature, and requirements for visual acuity, timing, and ability to coordinate with lifters and throwers became more important.

Conclusions

There were marked changes in match participation times, player size, and frequencies of Bledisloe Cup match activities between 1972 and 2004. The introduction of professionalism was associated with large increases in passes, tackles, rucks, tries, ball-in-play time, and body mass, whereas there were large reductions in participation time per player and kicks during play, and moderate reductions in lineouts and mauls. Noteworthy trends over time included a large increase in the number of rucks and a moderate decrease in the number of scrums. Good conditions were associated with large increases in tries and points scored, and with large decreases in kicks in play and participation time per player. Overall, the changes have resulted in increases in the pace and amount of physical contact in the sport.

Factors that might have contributed to these changes include modifications to laws and to the application of existing laws, development of match analysis systems, changes to match tactics, changes in clothing and equipment technology, and changes in the amount and content of physical and technical training of players. Future research could address whether the observed changes in rugby union have extended professional players' careers and further examine relationships between law changes and the subsequent impact on player characteristics and match activities.

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THESIS CHAPTER SEVEN

CONCLUSIONS

Conclusions

The preceding chapters provide an overview of work I have completed in rugby injury epidemiology, rugby injury prevention and patterns of rugby match activities whilst in the employ of the New Zealand Rugby Union since August 2000. The chapters and appendices are linked by virtue of the fact that they were aspects of rugby injury and performance that were of particular concern to the NZRU during the development and delivery of a real-world injury control programme. This means that the scope of the thesis is broader than many PhDs in injury epidemiology, which typically comprise a closely linked series of investigations into a single aspect of an injury issue.

RugbySmart represented one of the first, if not the first, sports injury prevention programme to combine nationwide delivery of injury prevention initiatives with a nationwide injury surveillance system. The nationwide surveillance system used ACC sports injury claim data combined with player numbers derived from the NZRU player registration database. In addition to the nationwide surveillance system, the NZRU developed bespoke injury surveillance and performance analysis systems that capture and analyse data on the entire population of New Zealand’s professional players. With respect to yielding knowledge for the purposes of developing and implementing injury prevention interventions, the systems are complementary. The ACC-based system provides information about all injuries that occur to rugby players in the country, but comparatively little information is collected about the circumstances of each injury, or the exposure of players. The NZRU system, on the other hand, collects in-depth information about the characteristics and frequency of match events and injuries among professional players, with match exposure accurately recorded.

Spinal Injuries

The conceptual model used to underpin RugbySmart was the ‘sequence of prevention’ popularized in the sporting context by Willem van Mechelen [23]. Spinal injuries are the only aspect of rugby injury contained in the thesis in which all four steps of this model were dealt with.

As noted in the preface, Step 1 in the sequence of prevention is to establish the size of an injury problem by determining the incidence and severity of the particular injury of interest. At the time RugbySmart began the incidence rate of spinal cord injuries in New Zealand, and most other countries in which rugby is played, was unknown. In New Zealand, ACC data on permanently disabling spinal injuries in rugby had been collected, but no long-term trends resulting from analysis of the data had been published. In addition, prior to 1998, there was no systematic method of counting rugby player numbers in New Zealand, which meant that injury data were limited to reports of incident numbers [2] rather than incident rates of injury [21]. In most other countries no information was available on the size of the population at risk (i.e., the number of players and their typical exposure to rugby). Estimates of playing populations were available for Australia and New Zealand from the mid (Australia) and late (New Zealand) 1990's onward but, as pointed out in Chapters 1 and 2, there were a number of caveats regarding the confidence that could be placed in the measurements of player numbers. This lack of information about player exposure, along with variations in injury reporting systems, injury definitions and study designs meant establishing the incidence of spinal injuries in rugby was difficult. The rate of spinal cord injury was estimated to be 2.7 per 100,000 players per year in New Zealand from 1996 to 2000 (assuming the number of players in 1996 and 1997 were the same as the average of those from 1998 to 2000), and 5.1 per 100,000 player in Australia over the same period. Information about the severity of spinal injuries was more easily accessible, as it could be garnered from case-report and case-series studies. The severity of spinal injuries ranged from death through to complete recovery, depending on the degree of damage sustained by the spinal cord.

Step 2 of the sequence of prevention is to identify risk factors associated with the injury issue. The risk factors highlighted for spinal injuries in rugby included particular types of tackle, scrum engagements and collapses, the playing position of players, and the time of the season. Although my review was an attempt to synthesise the knowledge that then existed, much of the material for the resulting RugbySmart programme with respect to spinal injuries was based on evidence from single case reports, retrospective studies of case series, and expert opinion. There were no prospective studies designed to identify risk factors for permanently disabling spinal injuries, and no studies based on interventions. The aforementioned limitations do not imply, however, that the information gleaned from the review was of little value. Case-report and case-series studies linking descriptions of injury with the subsequent anatomical and functional damage helped identify injury mechanisms and potential risk factors, as well as raising awareness of the issue of rugby-related spinal injuries among administrators, the sports medicine community, and the public at large.

Steps 3 and 4 of the sequence of prevention deal with the development, implementation, and the evaluation of those measures. The main intervention used for reducing spinal injuries among New Zealand rugby players was the participation of all coaches and referees in compulsory RugbySmart seminars. A secondary means of communicating injury prevention messages to coaches was via articles published in the NZRU coaching magazine 'GamePlan Rugby'. Appendices Two through Six provide examples of the breadth of issues that were covered in these articles. The GamePlan Rugby articles took information from the research papers presented in the body of the thesis and highlighted the findings in language more accessible to coaches. Because details of RugbySmart seminars are included in Chapters 2 and 3 of the thesis, I will not reiterate their content here, except to make one observation that is not contained in the published papers. In the first few years of the RugbySmart programme, I was concerned that there was a lack of understanding among rugby participants about the mechanisms of spinal injuries. Conversations with players and coaches had led me to the conclusion that they believed spinal injuries were primarily the result of 'bad luck'. To address this concern, graphic depictions of spinal cord injuries occurring in scrum and tackle situations were developed. These video clips showed how the cervical spine could undergo hyperflexion and dislocation with resulting damage to the spinal cord in scrums and tackles. It is my belief that there is now a much greater degree of understanding of not only how spinal injuries can occur in rugby, but also why participants need to understanding how to coach or develop safe techniques in the contact aspects of the sport.

The evaluation of the effectiveness of RugbySmart with respect to preventing spinal injuries was dealt with in Chapter 2 of the thesis. A paper reporting the personal view of a consultant general surgeon in England that contested scrums should be banned in rugby due to the risk of spinal injuries was published in the BMJ in 2006 [4]. The decision to publish the results of RugbySmart with respect to spinal injuries in the BMJ was made in part so that the paper would provide a rejoinder to the article calling for scrums to be banned. Chapter 2 was the first published paper to show a decrease in spinal injury incidence (from 2.7 to 1.3 per 100,000 players per year) among a population of rugby players following the introduction of an education-based injury prevention intervention. There was a decrease in spinal injuries from scrums associated with the introduction of RugbySmart, but no clear effect on reducing spinal injuries from other aspects of the sport.

Ecologic studies were used to evaluate the impact of the RugbySmart interventions on spinal injuries, and on other injuries discussed below. It appears that RugbySmart has contributed to a decrease in permanently disabling spinal injuries, dental injuries, non-disabling injuries to the neck/back/spine, shoulder, knee and leg (excluding knee and ankle) injuries. Ecologic studies are, however, subject to a number of biases that randomized controlled-trial methodology eliminates. Why then did I and others responsible for the design and administration of RugbySmart not use RCTs to evaluate RugbySmart? In an ideal world, we would have. An editorial in the BMJ that accompanied the paper examining the effect of RugbySmart on spinal injuries noted that, while an RCT to examine the impact of such injury prevention initiatives was desirable, it might be financially impractical. In fact, the impracticalities faced were not merely financial. The very low rate of permanently disabling injuries (estimated to be 2.7 injuries per 100,000 players per year from 1996 to 2000) meant that a study showing a 50% decrease in these injuries over a five-year period with precision similar to what we obtained would need double the sample size; that is, the *entire* population of rugby players in New Zealand in each group. In addition, the NZRU and ACC wished to run the programme on a nationwide basis from the outset, which precluded the use of an RCT. So, we were left in the position of saying that we introduced the RugbySmart programme, and that there was a concurrent drop in the number of spinal injuries in New Zealand rugby. We do not have sufficient evidence to state that the programme *caused* the decrease, because unmeasured factors may have been responsible. Unpublished information from ACC indicates that spinal injuries did not decline either in other sports or in non-sporting activities in New Zealand over the same period (Simon Gianotti, personal communication).

General Injury Epidemiology

Although spinal injuries were the focus of RugbySmart at the beginning of the programme, the mandate of RugbySmart was wider. Injuries that were targeted by ACC included dental injuries, non-disabling injuries to the neck/back/spine, shoulder, knee, ankle and leg (excluding knee and ankle) injuries. As was the case with spinal injuries, the ACC claims system was used as an injury surveillance system to evaluate the impact of the injury prevention measures used in RugbySmart on the subsequent incidence of injuries. As outlined in Chapter 3, most of the areas targeted showed reductions in injury incidence (ankle injuries were a notable exception) following the introduction of RugbySmart seminars. The wider evaluation of RugbySmart also indicates that the programme enjoyed a degree of success in changing the behaviour of players. Players were more likely to report participating in sessions containing instruction and practice on safety in the contact elements of the sport following the introduction of RugbySmart. There was also a substantial increase in the reported wearing rates of mouthguards and a corresponding decrease in dental-injury claims, although the intervention mandating mouthguard use in New Zealand occurred prior to the beginning of the RugbySmart programme.

Risk Factors for Tackle Injuries

The tackle was already known to be associated with a large proportion of rugby injuries. There was, however, a lack of knowledge about the aetiology of tackle-related injuries. The tackle study (Chapter 5) falls into step 2 of the sequence of prevention: identification of risk factors for a particular injury. Whereas the ecologic studies (the dental, spinal, and RugbySmart evaluation papers) used existing data sources, the data from the tackle study came from a template I designed specifically to identify and quantify risks associated with the tackle situation. The tackle study used a prospective methodology and permitted evaluation of incidence rates by both exposure time and tackle type.

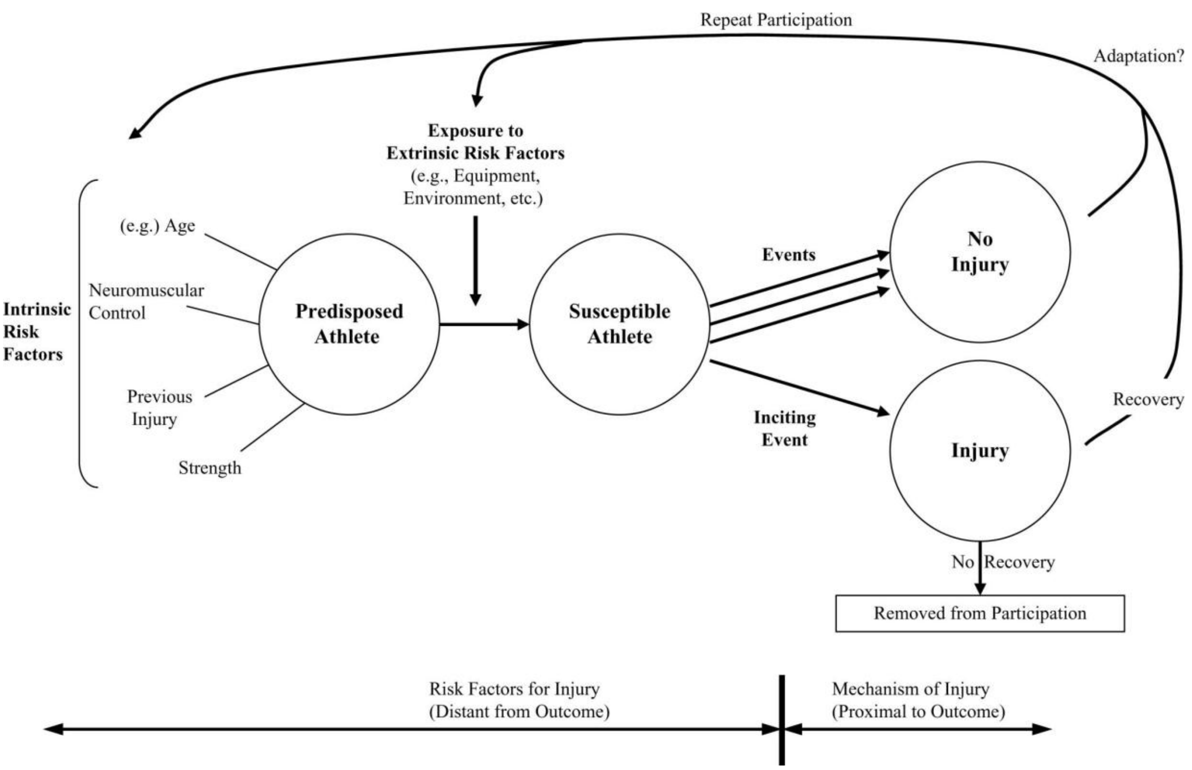
One issue that emerged during the analysis and write-up of the paper was that of how to appropriately communicate the level of risk involved in the tackle situation. Both the numerator (the criteria by which an injury is counted as a 'case') and the denominator (how exposure is measured) influence the perception of the level of risk. In the tackle paper, various options for reporting the numerator were available, including on-field injury assessments not requiring replacement, on-field assessments that did require replacement, and (for New Zealand based players) the length of time players were unavailable for selection due to a tackle injury. This last measure combines injury severity [23] with incidence, a measure we termed 'injury burden'. All of these measures provide different perspectives on the injury issue, a point noted by other researchers [5, 8, 14]. For reasons of space and simplicity, we ended up excluding on-field assessments that did not require replacement.

Reporting injuries using 1000 hours of play as a denominator provides insight as to the types of tackle injuries that most commonly occur in rugby, but does not allow judgements to be made about the types of tackles that carry the greatest risk per occurrence. Conversely, reporting injuries per 1000 tackles (or tackle events) permits evaluation of the riskiest tackles, but does not provide information about the frequency of injury occurrence. Providing both denominators is thus a useful approach.

Injury rates requiring player replacement were relatively low (~1 per 1000 tackles or ~ 6 per 1000 player-hours). We evaluated factors affecting these rates by positing a minimum clinically important difference (MCID) of 10%. This difference is probably below the limen for a given player, but we considered that it would represent a noticeable increase in costs and demands for medical service providers and insurers. There is little guidance in the literature as to what constitutes least clinically important differences in injury epidemiology or indeed in medical research generally. For example, the CONSORT statement [1, 17]for reporting randomized controlled trials mentions the need for a value of the MCID in estimation of sample size but offers no suggestions for what constitutes clinically relevant effects, while the STROBE statement [24, 25] for reporting observational studies makes brief mention only of 'clinical decision-making'. The concept of the MCID is implicit in the risk management principles recently promulgated by Fuller for sports injury [7, 8, 10], but this author provides only a generic discussion about acceptable levels of risk. Awareness of such principles combined with specific thresholds for MCIDs should help administrators make decisions about what type of changes to the tackle situation would be most acceptable to players, the medical community, spectators, and those who underwrite the costs of the sport.

Changes in Player Characteristics and Match Activities

The paper documenting changes in rugby activities is the only paper in the PhD that does not deal explicitly with injuries, although there is a link through to injury epidemiology. Meeuwisse and colleagues [16] developed the following conceptual model, which they proposed was capable of accounting for the multifactorial etiology of athletic injuries:



The 2007 model built on a previous version [15] that had not explicitly accounted for repeated exposure to events that have the potential to cause injury. The dynamic recursive model draws from the host-environment-agent model of classical epidemiology (with some of the risk factors associated with the 'host' or athlete explicated), and from the Haddon matrix [12], which outlines the sequence of events associated with an injury. In the Meeuwisse model, the 'agent' (i.e., transfer of energy) is subsumed under the term 'inciting event', which represents the circumstances and mechanism of the injury. These inciting events have received attention from sports physicians, as they lend themselves to analysis of specific mechanisms of injury. The major advantage of the Meeuwisse model in terms of understanding injury etiology lies in the fact that it accounts for multiple causal factors and the time sequence over which such factors act. One of the main conclusions of the article in which Meeuwisse and colleagues [16] presented their model was that 'exposure to a risk factor in sport cannot be seen as a static event, since the exposure is repeated under changing conditions. Therefore, both the design of the study and analysis strategy must accommodate changing risks.' The focus of Meeuwisse et al.'s paper is on the effects of repeated exposure on a given athlete without explicitly recognizing effects of longer-term changes in the sport itself. The paper examining changes in Bledisloe Cup rugby from 1972 to 2004 provides a clear example of how the risks to different populations of players involved in a given sport can evolve. This paper describes large changes in activities most associated with transfers of energy in international rugby – tackles, rucks, scrums and mauls – and in the anthropometric and physical performance characteristics of the players themselves. The findings reinforce the view of Meeuwisse et al. (2007) that those designing injury prevention programmes need to be aware that risks in a sport may change. Prevention programmes predicated on risk-factor studies may become less relevant over time as the game continues to develop and the patterns of energy transfer change. Thus, regular reappraisals of the typical player characteristics and activity patterns within rugby may be useful to ensure that prevention programmes are targeting the aspects of the sport that are currently contributing most to the injury burden.

Future Directions

Calls have been made since at least the early 1990’s to set up long-term, prospective registers of serious injuries in rugby [11, 18, 19]. RugbySmart answered this call in New Zealand by combining ACC injury surveillance data with NZRU player regristration information. The international rugby community is now receptive to meeting the challenges inherent in setting up similar systems in the other major rugby-playing nations. The IRB is currently planning to set up a group to oversee this project.

The focus of RugbySmart has been the prevention of injuries, but the effect of participation in rugby on the long-term health of players has received little attention. Although there is some cross-sectional evidence that playing rugby accelerates degeneration of the spinal column [3], there is a lack of evidence regarding the attributable risk of elite rugby on long-term musculoskeletal, neuropsychological and general health outcomes of participants. Providing answers to questions such as ‘what impact does a professional rugby career have on joint-health and the chances of developing osteoarthritis?’ and ‘does exposure to professional rugby affect long-term emotional and mental well being?’ are of major importance if the long-term health risks associated with rugby are to be properly managed. A prospective cohort study to quantify these risks could involve induction of all new professional players at Super 14 and Heineken Cup level over a five-year period into a cohort that is followed up over the next 20 years. Baseline assessments would include measurement of those factors already noted as risk factors for injury from existing studies (e.g., previous injuries) as well as a number of postulated risk factors where evidence is absent or sketchy (e.g., the prognostic value of neurocognitive status on future mental health outcomes). Although it would necessarily be a long-term project, many of the systems and processes required to capture information on professional players are extant. The consensus document on rugby-injury definitions [9] should assist with the standardization of medical reporting. Information about exposure to rugby (especially with respect to matches) can be derived from match analysis systems, along the lines of the information captured in the tackle study [22]. Post-career follow-up could be modeled on methods used in existing long-term prospective studies, such as the Dunedin Multidisciplinary Health and Development study [13, 20], and the Framingham Heart Study [6]. The information gained would allow much more informed decisions about managing the risk of participation in rugby to be made than is currently the case.

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APPENDIX 1

THE NEW ZEALAND RUGBY INJURY AND PERFORMANCE PROJECT. VI. A PROSPECTIVE COHORT STUDY OF RISK FACTORS FOR INJURY IN RUGBY UNION FOOTBALL

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Original articles

The New Zealand rugby injury and performance project. VI. A prospective cohort study of risk factors for injury in rugby union football

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Abstract
***Objectives*—Although the nature of rugby injury has been well documented, little is known about key risk factors. A prospective cohort study was undertaken to examine the association between potential risk factors and injury risk, measured both as an injury incidence rate and as a proportion of the playing season missed. The latter measure incorporates a measure of injury severity.**
***Methods*—A cohort of 258 male players (mean (SD) age 20.6 (3.7) years) were followed through a full competitive season. At a preseason assessment, basic characteristics, health and lifestyle patterns, playing experience, injury experience, training patterns, and anthropometric characteristics were recorded, and then a battery of fitness tests were carried out.**
***Results*—A multiple regression model identified grade and previous injury experience as risk factors for in season injury, measured as an injury incidence rate. A second model identified previous injury experience, hours of strenuous physical activity a week, playing position, cigarette smoking status, body mass index, years of rugby participation, stress, aerobic and anaerobic performance, and number of push ups as risk factors for in season injury, measured as proportion of season missed.**
***Conclusions*—The findings emphasise the importance of previous injury as a predictor of injury incidence and of missing play. They also show the importance of considering both the incidence rate and severity of injury when identifying risk factors for injury in sport.**
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Keywords: injury; epidemiology; risk factors; cohort; rugby union

Participation in physical activity and sport is often recommended as a means by which the risk of contracting many of the "diseases of the sedentary", such as coronary heart disease and cancer, can be reduced.[1 2] Recognition of this protective effect has led to programmes designed to promote the benefits of participation in sport and physical exercise and increase participation rates.[3] Little is known, however, about the risks and costs of participation in sport and other physical activity, partly because of a lack of epidemiological research.[4–7] Calls have been made for the application of epidemiological methods to the investigation of risk factors for injury resulting from sport and physical activity.[6] The undertaking of such studies has been hampered to some extent by methodological issues such as difficulties in setting up injury surveillance systems, defining sports injury, and the complexity of data analysis in cases in which participants sustain multiple injuries during a season of play.[8 9]

The multiplicity of factors that may contribute to injury from sporting activity, and the complexity of the relations among them, mean that identifying causal mechanisms poses a challenge to epidemiologists.[5 6] Potential risk factors have been classified into those intrinsic and those extrinsic to the sportsperson.[10] Intrinsic factors are specific to the individual, and include age, sex, anthropometric characteristics, fitness, psychological characteristics, health status, and injury history. Extrinsic factors are those external to the individual and include the nature of the sport, environmental conditions, and equipment.[10]

Most previous research attempting to investigate risk factors associated with sports injury has used the incidence rate as the outcome variable.[11–13] Studies that identify risk factors for sports injuries and recommend interventions based only on injury incidence rates may be missing an important part of the impact of injury on players—that is, the severity of the injury. Measuring the proportion of the season missed as the result of injury is one method of generating a proxy measure of injury severity.[9] The identification of risk factors associated with the effect of the injury on subsequent participation may be as important in understanding how to reduce the burden of injuries on sports participants as identifying factors associated with the injury incidence rate.

A recent prospective study into intrinsic risk factors for injuries resulting from physical activity identified previous injury and exposure

Table 1 Potential risk factors for rugby injury, measured before the season

Rugby specific risk factors	*Basic, psychological, and lifestyle factors*	*Anthropometric, physical performance, and training factors*
Grade (level of play)	Age	Anthropometric characteristics
Years of rugby participation	Ethnic origin	Height
Representative experience	Strenuous physical activity (hours/week)	Body mass
Playing position	Psychological wellbeing	Body mass index (BMI)
Injury experience:	Competition anxiety	Sum of six skinfolds
No injury in previous 12 months	Alcohol use	Physical fitness
Previous season	Cigarette smoking:	Aerobic endurance (20 m multistage shuttle run test)
	Non-smoker	Anaerobic endurance (repeated high intensity shuttle run test)
	Ex-smoker	30 m sprint time (5 m running start)
	Current smoker	Vertical jump
		Push ups
		Weekly endurance training load

time as being more important predictors of injury incidence rate than psychological, psychosocial, physiological, and anthropometric measures.[11] A study of army trainees found that greater age, higher cigarette consumption, previous low physical activity levels, high or low flexibility, and low levels of aerobic fitness were associated with a higher risk of injury.[12 13]

Rugby union football (rugby) is a vigorous contact sport, which enjoys particular popularity in Australia, Britain, France, New Zealand, and South Africa. The nature and incidence of rugby injuries have been well documented, with cervical spine injuries receiving particular attention.[14–22] In New Zealand, the combination of a large player base (about 120 000 in a population of 3.8 million people) and a high incidence of injury[23] result in rugby being the largest contributor to sports injury costs borne by New Zealand's mandatory injury compensation scheme administered by the Accident Compensation Corporation (ACC).[24]

From what is known about rugby injury, it appears that there is a higher incidence at higher grades, although the incidence rate of particular injuries—for example, spinal cord injuries—does not always follow this pattern.[14–16 21] The types of injury a player is likely to sustain are also related to playing position—for example, those in the front row positions are more at risk of cervical spine injury during scrums than those in other positions.[20 21] The tackle appears to be the phase of play associated with the greatest risk of injury overall.[17]

Given the limited information available on risk factors for sports injury in general and the lack of analytical studies on rugby injuries, the New Zealand Rugby Injury and Performance Project (RIPP)[25] was undertaken to examine a wide range of extrinsic and intrinsic factors postulated to be associated with rugby injury. The purpose of this paper is to explore the associations between potential risk factors for rugby injury, as assessed before the season, and both injury incidence during the season and the proportion of the season missed because of injury, using information obtained from the RIPP.

Methods

SUBJECTS AND STUDY DESIGN

The RIPP was a prospective cohort study in which rugby players were recruited at the beginning of a rugby playing season and then followed on a weekly basis until the end of the same season. At the beginning of the 1993 rugby season, 356 rugby players (258 men and 92 women) were enrolled in the RIPP. Players were recruited into the study through five rugby clubs and four secondary schools. The study design, basic characteristics, anthropometric and physical performance attributes, alcohol use, and patterns of previous injury of the RIPP cohort members have been reported elsewhere.[18 25–29] This paper examines risk factors for the male players only; the sample of female players was too small to allow reliable estimates of the various risk factors to be calculated independently.

PRESEASON ASSESSMENT

Players completed a preseason assessment that involved completing a single self administered questionnaire and undergoing a series of anthropometric and physical fitness assessments. The assessment lasted approximately 2.5 hours.[25] Table 1 gives the factors measured at the preseason assessment. The previous injury experience of players was classified as follows: players who had not sustained an injury in the previous season (no injury in previous 12 months), those who had been injured during the previous season but were not currently injured at the preseason assessment (previous season), and those who reported that they were injured at the time of the preseason assessment (preseason injury). Players were asked to estimate how many hours a week, in the previous four weeks, they had spent in "strenuous physical activity" (not further defined). Alcohol use was assessed using the Alcohol Use Disorders Identification Test (AUDIT).[30] The AUDIT is a 10 item questionnaire used to screen people for hazardous or harmful alcohol consumption. A score of 8 or more is taken to indicate an alcohol use disorder. Competition anxiety was measured by the Sport Competition Anxiety Test (SCAT).[31] The SCAT is a 15 item measure of competitive trait anxiety. Scores range from 10 to 30, with a higher score indicating a higher level of anxiety. Psychological wellbeing was measured using the General Health Questionnaire (GHQ).[32] The GHQ is a self administered screening questionnaire which measures general psychological distress. The 12 item version of the GHQ was used.

The anthropometric and physical fitness measurements were taken upon completion of the questionnaire. The methods used are described in detail elsewhere.[28] Anthropometric measurements taken from the players included height (m), body mass (kg), and skinfolds from six sites (triceps, subscapular, suprailiac, abdomen, mid thigh, and medial calf). The sum of skinfolds from these six sites was used as a measure of body fatness, as was body mass index (BMI) (kg/m^2). The physical fitness measures examined were a 20 m multistage shuttle run for aerobic endurance,[33] number of push ups performed at a constant cadence until this could no longer be maintained, vertical jump height (best of three), sprinting 30 m from a 5 m running start, and a set of repeated high intensity shuttles.[28 29 33 34] Weekly endurance training load was calculated from the players' reported intensity, duration, and frequency of aerobic training. Time and resource constraints precluded the measurement of strength and flexibility.

IN SEASON FOLLOW UP

The in season follow up consisted of a weekly telephone interview conducted with each player. Nine trained interviewers collected information about rugby exposure (number of games and practices attended, warm ups, grade, playing position, involvement in foul play, use of protective equipment) and any injuries sustained (site, type, description of how the injury occurred, medical attention received, treatment, whether the injury caused the player to miss any games or practices, whether the injury was the result of foul play). An injury event was defined as one that caused the player to either miss at least one game or scheduled team practice, or to seek medical attention.[25] During most of the 23 weeks of the club season, interviews were completed with 90–95% of players. Overall, 90% of attempted interviews were completed.[25]

OUTCOME MEASURES

Two outcome measures were chosen to examine the influence of the preseason factors on injury experience during the season. These were the injury incidence rate (IR) and the proportion of the season a player missed because of injury (PM). IR (per 1000 player hours) was calculated as follows: IR = 1000 × (number of injury events that occurred during games/(1.33 × number of games played)). Each game of rugby lasts 80 minutes, hence the multiplication by 1.33 to convert games played to hours of play.

To calculate the proportion of the season missed, players who did not miss any games were considered to have completed the season with no missed time (PM = 0). For the purposes of calculating PM, any practices they missed because of injury in a particular week were ignored. PM was calculated as follows: PM = number of weeks in which game(s) were missed because of injury in games/number of weeks in which one or more games was played. For weeks in which there was no follow up interview, the entire week was ignored. Although this would have the effect of inflating PM, given that 90% of attempted interviews were completed, this effect was not expected to be large or to introduce any systematic bias.

These two outcome measures were chosen to provide complementary information. The two measures are not independent, but both were used to examine whether specific risk factors were related to different measures of injury. IR provides a measure of the number of injuries sustained per unit of exposure to rugby games, whereas PM provides a proxy measure of injury severity.[9]

ANALYSES

A total of 258 male rugby players completed the questionnaire and at least part of the physical assessment. The univariate associations between potential risk factors and the two outcome measures (IR and PM) were examined first. Categorical variables were created from continuous variables by assigning players to quintiles (for instance, on the basis of their performance on each of the fitness tests). The relative risk (RR) of sustaining a greater incidence of injuries or of missing a greater proportion of the season because of injury was calculated for each level of the variable compared with one of the levels chosen as the reference level. Ninety five percent confidence intervals (95% CI) for the relative risk ratios were calculated. Differences between groups were regarded as significant if the 95% CI did not include 1.00—that is the level of significance, $p<0.05$.

Associations between risk factors and the two outcome measures were assessed using multiple logistic regression. Overdispersion was controlled for in both outcomes, using variance inflation factors based on the deviance χ^2 values. The regression analyses were performed using the SAS[35] GENMOD procedure.

Results

UNIVARIATE ANALYSES

Rugby specific factors

Table 2 shows the univariate associations between rugby specific factors and both IR and PM. Players from higher grades sustained a higher rate of injuries than players in the reference group (under 19/18 grades). Players at senior A level reported the highest rate of injuries. Players who reported a preseason injury (an injury that was affecting their ability to train or play at the time of the preseason assessment) had a higher IR than those who had no injuries during the previous season (RR = 2.41; 95% CI = 1.34 to 4.32).

There were no significant differences in PM by grade. In terms of positional groups, midfield backs missed a greater proportion of their season than the reference group (RR = 2.55; 95% CI = 1.29 to 5.04). Players who had played rugby for zero to three years before the 1993 season missed the greatest proportion of their season (16%), and were selected as the reference group for comparisons of risk associated with rugby experience. Those who had participated for four to five years missed less play because of injury (7%) compared with the reference group (RR = 0.42; 95% CI = 0.21 to 0.87). Those who had a preseason injury missed a greater proportion of their season (17%) than players with no injuries in the previous 12 months (8%) (RR = 2.25; 95% CI = 0.99 to 5.11).

Table 2 Rugby specific risk factors for injury incidence rate and proportion of playing season missed

		Injury incidence rate (per 1000 hours)			Proportion of season missed		
Factor	N	Rate	RR (95% CI)	p Value	Proportion	RR (95% CI)	p Value
Grade							
Under 19/18 (Reference)	53	47	1.00		0.10	1.00	
Under 21	64	80	1.84 (1.17 to 2.89)	<0.01	0.11	1.04 (0.56 to 1.93)	0.91
Senior B	37	81	1.85 (1.11 to 3.07)	0.02	0.12	1.09 (0.54 to 2.19)	0.79
Senior A	90	106	2.50 (1.67 to 3.74)	<0.01	0.12	1.11 (0.63 to 1.95)	0.71
Playing position*							
Front Row (Reference)	38	89	1.00		0.09	1.00	
Locks	34	98	1.10 (0.69 to 1.76)	0.66	0.09	0.91 (0.40 to 2.08)	0.82
Loose forwards	58	77	0.85 (0.54 to 1.33)	0.48	0.11	1.21 (0.60 to 2.44)	0.59
Inside backs	38	69	0.75 (0.45 to 1.22)	0.23	0.07	0.76 (0.33 to 1.76)	0.52
Midfield backs	40	77	0.85 (0.52 to 1.41)	0.52	0.21	2.55 (1.29 to 5.04)	<0.01
Outside backs	40	83	0.92 (0.57 to 1.49)	0.73	0.12	1.33 (0.63 to 2.80)	0.44
Years of rugby participation							
0 to 3 years (Reference)	52	97	1.00		0.16	1.00	
4 to 5 years	42	79	0.80 (0.51 to 1.24)	0.31	0.07	0.42 (0.21 to 0.87)	0.02
6 to 7 years	55	75	0.75 (0.49 to 1.14)	0.16	0.10	0.56 (0.31 to 1.03)	0.06
8 years	47	69	0.69 (0.43 to 1.09)	0.11	0.10	0.58 (0.30 to 1.09)	0.08
>8 years	52	89	0.91 (0.61 to 1.38)	0.66	0.13	0.76 (0.43 to 1.33)	0.32
Representative experience (previous 12 months)							
No (Reference)	138	78	1.00		0.12	1.00	
Yes	103	89	1.16 (0.88 to 1.54)	0.27	0.10	0.80 (0.52 to 1.22)	0.28
Injury experience							
No injuries in previous 12 months (Reference)	22	50	1.00		0.08	1.00	
Previous season	139	75	1.57 (0.88 to 2.80)	0.11	0.10	1.21 (0.54 to 2.72)	0.64
Preseason	83	109	2.41 (1.34 to 4.32)	<0.01	0.17	2.25 (0.99 to 5.11)	0.05

*Positional groups (position names as specified by International Rugby Board Regulation 14.1): front row (loose head prop, hooker, tight head prop); locks (left lock, right lock); loose forwards (left flanker, right flanker, number eight); inside backs (scrum half, fly half); midfield backs (left centre, right centre); outside backs (left wing, right wing, full back).

Basic, psychological, and lifestyle factors

Table 3 gives the associations between basic, psychological, and lifestyle factors and both IR and PM. The relative risk of injury incidence increased with age when compared with those in the reference group (17 years and under). IR also tended to increase with higher levels of strenuous physical activity, but the increases were not significant when compared with the reference group. Ex-smokers sustained a higher

Table 3 Basic, psychological, and lifestyle risk factors for injury incidence and proportion of playing season missed

		Injury incidence rate (per 1000 hours)			Proportion of season missed		
Factor	N	Rate	RR (95% CI)	p Value	Proportion	RR (95% CI)	p Value
Age group							
17 and under (Reference)	41	50	1.00		0.10	1.00	
18 to 19	75	76	1.60 (0.99 to 2.57)	0.05	0.11	1.06 (0.54 to 2.10)	0.86
20 to 22	79	94	2.03 (1.28 to 3.19)	<0.01	0.11	1.07 (0.55 to 2.10)	0.83
23 and over	53	101	2.19 (1.36 to 3.53)	<0.01	0.16	1.69 (0.86 to 3.29)	0.12
Ethnic origin							
NZ Maori/Pacific Islander (Reference)	44	74	1.00		0.13	1.00	
European	203	83	1.13 (0.77 to 1.67)	0.50	0.12	0.90 (0.53 to 1.55)	0.70
Strenuous physical activity (hours/week)							
<5 (Reference)	38	68	1.00		0.13	1.00	
5 to 9	97	76	1.12 (0.71 to 1.77)	0.61	0.10	0.78 (0.41 to 1.46)	0.44
10 to 19	54	83	1.25 (0.76 to 2.04)	0.36	0.10	0.76 (0.38 to 1.52)	0.43
20 to 39	22	83	1.25 (0.69 to 2.27)	0.44	0.10	0.77 (0.32 to 1.89)	0.57
>39	29	105	1.63 (0.96 to 2.77)	0.06	0.21	1.86 (0.95 to 3.68)	0.07
Cigarette smoking							
Non-smoker (Reference)	168	77	1.00		0.10	1.00	
Ex-smoker	36	110	1.49 (1.04 to 2.14)	0.02	0.15	1.65 (0.96 to 2.84)	0.06
Current Smoker	42	79	1.02 (0.68 to 1.54)	0.91	0.18	2.11 (1.28 to 3.47)	<0.01
Alcohol use (AUDIT score)							
<8 (Reference)	54	77	1.00		0.16	1.00	
8 to 10	53	77	1.00 (0.65 to 1.54)	0.99	0.09	0.55 (0.29 to 1.01)	0.05
11 to 12	40	92	1.23 (0.79 to 1.92)	0.36	0.12	0.74 (0.39 to 1.39)	0.34
13 to 16	50	80	1.05 (0.68 to 1.64)	0.81	0.12	0.73 (0.40 to 1.31)	0.28
17 to 30	51	86	1.14 (0.74 to 1.77)	0.54	0.09	0.55 (0.29 to 1.05)	0.06
Self rated health status							
Very good (Reference)	103	80	1.00		0.12	1.00	
Good	130	84	1.06 (0.80 to 1.42)	0.67	0.12	0.94 (0.62 to 1.44)	0.78
Not too good	12	62	0.76 (0.38 to 1.53)	0.44	0.06	0.42 (0.12 to 1.56)	0.19
General Health Questionnaire (score)							
0 (Reference)	196	77	1.00		0.12	1.00	
1	54	100	1.34 (0.96 to 1.85)	0.08	0.11	0.95 (0.55 to 1.60)	0.84
Stress (previous 4 weeks)							
None (Reference)	52	73	1.00		0.08	1.00	
A little	126	87	1.22 (0.85 to 1.77)	0.26	0.14	1.70 (0.96 to 3.02)	0.06
Somewhat	61	74	1.02 (0.67 to 1.56)	0.91	0.10	1.15 (0.58 to 2.26)	0.69
A lot	9	128	1.92 (0.97 to 3.84)	0.06	0.11	1.30 (0.38 to 4.42)	0.67
SCAT (score)							
<18 (Reference)	43	77	1.00		0.12	1.00	
18 to 20	68	80	1.03 (0.66 to 1.60)	0.88	0.13	1.10 (0.59 to 2.04)	0.76
21 to 22	41	82	1.07 (0.66 to 1.74)	0.79	0.11	0.90 (0.44 to 1.81)	0.76
23 to 25	47	83	1.08 (0.67 to 1.74)	0.74	0.13	1.09 (0.56 to 2.13)	0.79
26 to 30	47	89	1.18 (0.75 to 1.88)	0.47	0.09	0.73 (0.36 to 1.49)	0.38

Table 4 Anthropometric, physical performance, and training factors for injury incidence and proportion of playing season missed

		Injury incidence rate (per 1000 hours)			Proportion of season missed		
Factor	N	Rate	RR (95% CI)	p Value	Proportion	RR (95% CI)	p Value
Height (cm)							
<174 cm (Reference)	46	70	1.00		0.08	1.00	
174 to 178 cm	53	67	0.96 (0.60 to 1.54)	0.86	0.11	1.39 (0.69 to 2.81)	0.34
179 to 181 cm	50	95	1.40 (0.90 to 2.18)	0.12	0.16	2.04 (1.05 to 3.97)	0.03
182 to 185 cm	46	84	1.24 (0.78 to 1.97)	0.36	0.14	1.72 (0.85 to 3.46)	0.12
>185 cm	53	93	1.38 (0.90 to 2.13)	0.12	0.09	1.10 (0.53 to 2.29)	0.78
Body mass (kg)							
<74 kg (Reference)	50	56	1.00		0.10	1.00	
74 to 80 kg	52	80	1.50 (0.93 to 2.41)	0.08	0.11	1.16 (0.59 to 2.26)	0.66
81 to 87 kg	46	92	1.77 (1.09 to 2.86)	0.02	0.17	1.85 (0.98 to 3.49)	0.05
87 to 94 kg	51	89	1.70 (1.08 to 2.68)	0.02	0.11	1.09 (0.56 to 2.13)	0.79
>94 kg	49	95	1.81 (1.15 to 2.87)	0.01	0.11	1.09 (0.55 to 2.17)	0.79
Body mass index (BMI)							
<23 (Reference)	40	55	1.00		0.14	1.00	
23 to 25	56	72	1.34 (0.80 to 2.24)	0.25	0.10	0.68 (0.35 to 1.32)	0.24
25 to 26.5	58	83	1.58 (0.96 to 2.59)	0.06	0.14	1.03 (0.56 to 1.89)	0.93
26.5 to 28	44	103	2.02 (1.22 to 3.34)	<0.01	0.11	0.81 (0.41 to 1.59)	0.53
>28	50	94	1.82 (1.11 to 2.96)	0.01	0.09	0.64 (0.32 to 1.26)	0.18
Sum of six skinfolds (mm)							
<48.2 (Reference)	48	66	1.00		0.12	1.00	
48.2 to 57.9	49	76	1.16 (0.73 to 1.88)	0.51	0.13	1.08 (0.57 to 2.04)	0.80
58.0 to 70.5	48	97	1.54 (0.97 to 2.42)	0.06	0.13	1.14 (0.60 to 2.14)	0.69
70.6 to 87.7	47	74	1.14 (0.71 to 1.85)	0.58	0.12	1.04 (0.54 to 2.00)	0.91
>87.7	50	95	1.51 (0.97 to 2.35)	0.06	0.08	0.67 (0.33 to 1.34)	0.25
Aerobic endurance (20 m multistage shuttle run test - repeats)							
<97 (Reference)	47	75	1.00		0.11	1.00	
97 to 105	48	70	0.91 (0.57 to 1.46)	0.70	0.13	1.16 (0.60 to 2.23)	0.65
106 to 117	47	80	1.06 (0.67 to 1.67)	0.80	0.12	1.03 (0.53 to 2.01)	0.93
118 to 128	48	99	1.36 (0.89 to 2.08)	0.15	0.10	0.88 (0.45 to 1.73)	0.71
>128	52	82	1.09 (0.70 to 1.70)	0.69	0.12	1.00 (0.52 to 1.96)	0.98
Anaerobic endurance (high intensity shuttle run test)							
>83 (Reference)	47	71	1.00		0.11	1.00	
65 to 83	49	70	0.97 (0.61 to 1.56)	0.92	0.13	1.23 (0.64 to 2.38)	0.53
51 to 64	47	98	1.42 (0.91 to 2.26)	0.11	0.15	1.49 (0.78 to 2.85)	0.22
37 to 50	47	86	1.25 (0.79 to 1.97)	0.34	0.13	1.20 (0.61 to 2.37)	0.58
<37	46	86	1.24 (0.80 to 1.94)	0.33	0.08	0.73 (0.35 to 1.56)	0.41
30 m sprint time (seconds)							
>4.06 (Reference)	48	85	1.00		0.11	1.00	
3.96 to 4.06	41	62	0.70 (0.44 to 1.13)	0.13	0.09	0.83 (0.40 to 1.70)	0.60
3.85 to 3.95	49	79	0.92 (0.60 to 1.40)	0.70	0.11	0.99 (0.52 to 1.91)	0.98
3.76 to 3.84	41	67	0.76 (0.48 to 1.24)	0.27	0.11	1.00 (0.49 to 2.06)	0.99
<3.76	39	121	1.51 (0.99 to 2.30)	0.05	0.17	1.66 (0.87 to 3.19)	0.11
Vertical jump (cm)							
<53.9 (Reference)	46	87	1.00		0.13	1.00	
53.9 to 58.2	48	83	0.95 (0.61 to 1.49)	0.82	0.12	0.91 (0.48 to 1.72)	0.76
58.3 to 61.0	46	73	0.82 (0.52 to 1.30)	0.39	0.07	0.51 (0.25 to 1.06)	0.07
61.1 to 65.0	47	79	0.90 (0.57 to 1.41)	0.64	0.10	0.75 (0.38 to 1.45)	0.38
>65.0	47	92	1.06 (0.68 to 1.66)	0.80	0.16	1.22 (0.66 to 2.24)	0.52
Push ups (number)							
<20 (Reference)	39	74	1.00		0.06	1.00	
20 to 23	49	83	1.13 (0.71 to 1.82)	0.59	0.15	2.69 (1.24 to 5.84)	0.01
24 to 28	50	83	1.13 (0.71 to 1.80)	0.60	0.13	2.30 (1.06 to 5.03)	0.03
29 to 33	51	95	1.33 (0.84 to 2.11)	0.22	0.12	2.19 (0.99 to 4.81)	0.05
>33	40	66	0.88 (0.52 to 1.48)	0.61	0.09	1.49 (0.62 to 3.55)	0.36
Endurance training load							
0 (Reference)	60	70	1.00		0.13	1.00	
1 to 9	72	80	1.17 (0.78 to 1.74)	0.44	0.10	0.74 (0.42 to 1.33)	0.31
10 to 14	54	98	1.46 (0.97 to 2.21)	0.06	0.10	0.74 (0.40 to 1.39)	0.34
15 to 20	30	87	1.29 (0.78 to 2.12)	0.31	0.17	1.34 (0.70 to 2.57)	0.37
>20	27	77	1.12 (0.67 to 1.88)	0.65	0.12	0.92 (0.44 to 1.90)	0.81

rate of injuries than non-smokers (RR = 1.15; 95% CI = 1.04 to 2.14). There was no significant difference between the IR of non-smokers and current smokers.

Although the difference in PM between the reference group (less than five hours of strenuous physical activity a week) and each of the other groups was not significant, activity for between five and 39 hours a week appeared to have a protective effect, whereas activity for more than 39 hours a week appeared to increase the risk of missing play (RR = 1.86; 95% CI = 0.95 to 3.68).

Current smokers (18%) missed a greater proportion of their season than did non-smokers (10%) (RR = 2.11; 95% CI = 1.28 to 3.47). The difference in PM between non-smokers and ex-smokers (15%) was not significant (RR = 1.65; 95% CI = 0.96 to 2.84).

Players who scored 8–10 points on the AUDIT missed a smaller proportion of their season (9%) than players who scored less than 8 points (16%) (RR = 0.55; 95% CI = 0.29 to 1.01). The other groups (>10 points) also missed a smaller proportion of their season (9–12%), although the differences in these cases were not significant. There appeared to be no consistent dose-response relation between AUDIT scores and either IR or PM.

Anthropometric, physical performance, and training factors

Table 4 gives the results for the anthropometric, physical performance, and training variables. Players with a body mass of greater than 81 kg sustained a higher IR than players whose body mass was less than 74 kg. Players with a

Table 5 *Risk factors for injury incidence rate and proportion of season missed controlling for effects of other risk factors in the models*

	Injury incidence rate (per 1000 hours)		Proportion of season missed	
Factor	Odds ratio (95% CI)	p Value	Odds ratio (95% CI)	p Value
Injury experience				
No injuries in previous 12 months (Reference)	1.00		1.00	
Previous season	1.24 (0.70 to 2.18)	0.45	1.46 (0.63 to 3.37)	0.37
Preseason	1.81 (1.01 to 3.25)	0.04	2.76 (1.13 to 6.72)	0.02
Grade				
Under 19/18 (Reference)	1.00			
Under 21	1.84 (1.18 to 2.87)	<0.01		
Senior B	1.69 (1.02 to 2.80)	0.04		
Senior A	2.35 (1.57 to 3.51)	<0.01		
Playing position				
Front row (Reference)			1.00	
Lock			0.67 (0.25 to 1.77)	0.40
Loose forwards			1.06 (0.44 to 2.56)	0.89
Inside backs			0.40 (0.14 to 1.20)	0.10
Midfield backs			1.73 (0.66 to 4.53)	0.26
Outside backs			1.06 (0.37 to 3.04)	0.92
Years rugby participation				
0 to 3 years (Reference)			1.00	
4 to 5 years			0.42 (0.19 to 0.93)	0.03
6 to 7 years			1.11 (0.57 to 2.18)	0.76
8 years			0.58 (0.29 to 1.16)	0.12
>8 years			1.44 (0.71 to 2.89)	0.30
Strenuous physical activity (hours/week)				
<5 (Reference)			1.00	
5 to 9			1.21 (0.56 to 2.63)	0.62
10 to 19			1.14 (0.49 to 2.63)	0.76
20 to 39			1.19 (0.44 to 3.23)	0.73
>39			3.71 (1.58 to 8.72)	<0.01
Cigarette smoking				
Non-smoker (Reference)			1.00	
Ex-smoker			1.86 (1.02 to 3.38)	0.04
Current smoker			1.97 (1.13 to 3.43)	0.01
Stress (previous 4 weeks)				
None (Reference)			1.00	
A little			2.50 (1.34 to 4.66)	<0.01
Somewhat			2.03 (0.97 to 4.22)	0.05
A lot			1.57 (0.45 to 5.47)	0.47
Body mass index (BMI)				
<23 (Reference)			1.00	
23 to 24.9			0.31 (0.14 to 0.67)	<0.01
25 to 26.4			0.31 (0.15 to 0.66)	<0.01
26.5 to 27.9			0.32 (0.14 to 0.71)	<0.01
>27.9			0.24 (0.10 to 0.63)	<0.01
Aerobic endurance (20 m multistage shuttle run test - repeats)				
≤96 (Reference)			1.00	
97 to 105			1.92 (0.94 to 3.92)	0.07
106 to 117			0.74 (0.34 to 1.62)	0.44
118 to 127			0.58 (0.25 to 1.35)	0.19
>127			1.27 (0.52 to 3.07)	0.59
Anaerobic endurance (high intensity shuttle run test)				
>83 (Reference)			1.00	
65 to 83			2.78 (1.28 to 6.04)	<0.01
57 to 64			2.73 (1.28 to 5.83)	<0.01
37 to 50			1.64 (0.73 to 3.67)	0.22
<37			1.63 (0.67 to 4.00)	0.27
Push ups (number)				
≤19 (Reference)			1.00	
20 to 23			4.42 (1.85 to 10.53)	<0.01
24 to 28			3.88 (1.65 to 9.14)	<0.01
29 to 33			3.52 (1.43 to 8.65)	<0.01
>33			2.68 (1.05 to 6.85)	0.04

BMI of greater than 26.5 sustained more injuries than players with a BMI of less than 23 (the reference group). Among the various physical performance tests, the 30 m sprint from a 5 m running start was the only one for which a significant difference in IR was observed across the groups. Players in the fastest group (<3.76 seconds) reported a higher IR than those in the slowest (reference) group (>4.06 seconds) (RR = 1.51; 95% CI = 0.99 to 2.30).

There were few associations between anthropometric and physical performance variables and PM. Players whose height was in the middle quintile (179–181 cm) missed a greater proportion of their season (16%) than the shortest players (<174 cm), who missed 8% of their season (RR = 2.04; 95% CI 1.05 to 3.97). Likewise, players whose body mass fell in the middle quintile (81–87 kg) missed a greater proportion of their season (17%) than players with the lowest body mass (<74 kg), who missed 10% of their season (RR = 1.85; 95% CI = 0.98 to 3.49). Players who performed between 20 and 33 push ups missed a greater proportion of their playing season than those who completed fewer than 19 push ups.

MULTIVARIATE ANALYSES

Variables were included in the multivariate modelling on the basis of either significant univariate associations with IR or PM, or, in the case of the physical performance measures, to represent distinct aspects of physical fitness. The following variables were included in the multivariate analyses: grade, age group, playing position, years of rugby participation, previous or preseason injury, cigarette smoking status, alcohol use, amount of strenuous physical activity in the off season, how stressful the player found the previous four weeks, endurance training load during the off season, aerobic shuttle test, time taken to sprint 30 m from a 5 m running start, anaerobic shuttle test, push ups, vertical jump, and BMI. Table 5 summarises the results of the multivariate analyses.

Grade and having an injury at the beginning of the rugby season were the only variables significantly associated with IR in the multivariate analysis. The risk profiles for these variables remained the same as for the univariate analyses. Players in the under 19/18 grades had a lower IR than players at all higher grades, and players who were injured at the preseason assessment had a higher IR than players who entered the season injury free (RR = 1.81; 95% CI = 1.01 to 3.25). Variables that were significant in the univariate analysis but did not remain in the multivariate model were age group, cigarette smoking status, body mass, BMI, and 30 m sprint time.

The variables that remained in the multivariate model for PM were previous injury experience, position, BMI, amount of strenuous physical activity, cigarette smoking status, stress in the last four weeks, years of rugby participation, both the aerobic and anaerobic shuttle tests, and push ups.

Although there were no significant differences in PM between positions when compared with front row players, locks and inside backs missed less of their playing season and midfield backs more. Players who were injured at the time of the preseason assessment missed a greater proportion of the season than those who reported no previous injury (RR = 2.76; 95% CI = 1.13 to 6.72). With respect to years of rugby participation, those who had played rugby for between four and five years missed a smaller proportion of their season because of injury than those who had played for three years or less (RR= 0.42; 95% CI = 0.19 to 0.93).

Players who engaged in strenuous physical activity for 39 hours or more a week missed a greater proportion of the season than did players who were active for five hours or less a week (RR = 3.71; 95% CI =1.58 to 8.72). Ex-smokers (RR = 1.86; 95% CI =1.02 to 3.38) and current smokers (RR = 1.97; 95% CI =1.13 to 3.43) had higher risks of missing time during their season than non-smokers.

For players whose BMI was less than 23, the risk of missing play was higher than for any of the other groups. There were differences in PM for the various levels on the aerobic shuttle test, but no consistent trend emerged. Players who became fatigued the quickest on the anaerobic shuttle test—that is, the worst performed group—missed a smaller proportion of their season than the players in the next two quintiles (RR = 2.78; 95% CI =1.28 to 6.04 and RR = 2.73; 95% CI = 1.28 to 5.83 respectively). Players at higher levels were not significantly different. Players who completed between 20 and 34 push ups missed a greater proportion of their season than those who completed 19 push ups or less.

Discussion

The use of two outcome variables enabled risk factors associated with two "dimensions" of rugby injury to be examined: injury rate and time lost because of injury. IR provided information about the incidence of injuries sustained by players given their exposure time. PM measured the proportion of potential playing time lost as the result of injury, providing a proxy measure of injury severity.[9] No previous prospective studies examining rugby injury have reported PM as an outcome. Although there was some overlap, most of the risk factors associated with PM were not associated with IR.

RUGBY SPECIFIC RISK FACTORS

Grade

Grade was identified as a significant risk factor for IR but not for PM. Players from higher grades reported higher incidence rates than players from lower grades. This finding is consistent with those of other studies.[14 17] Several explanations of why such a pattern was observed in this study can be proposed. It may be that players at higher grades reported a greater number of less severe injuries than players at lower grades, because of their better access to medical services. That is, they may have been more likely to receive medical attention for a given injury event, which would then qualify the event for inclusion in the study. With poorer access to medical services, players in lower grades may have treated the same injuries themselves or ignored them.

Alternatively, players from higher grades may have had a higher incidence of injury of equivalent severity than players at lower grades, but returned to play sooner after sustaining an injury. Again this may be a result of better access to medical services. Finally, the higher IR apparent among the higher grades may be associated with the greater size of the players[28] and the faster pace at which the game is played. These factors result in greater forces during the contact phases of the game, leading to greater trauma.[14 17] Players at the higher levels are generally highly motivated to return to play and are under pressure to retain their place in the team.

Position

Previous research findings on the level of risk associated with the various positions are equivocal.[14 15 22] Most previous studies, however, have only examined the proportion of injuries sustained by each positional group, without taking the relative exposure of the players into account. Although position was not found to be a significant risk factor for IR, the midfield backs missed a significantly greater proportion of their season than did the reference group (front row). This finding may reflect the different roles of these players in the game. Midfield backs are often used as "battering rams" to run the ball directly at the opposing players. The frequency with which they are required to do this and the high speeds they attain when they enter tackles may have contributed to the increased risk observed in this study. The midfield backs missed, on average, 21% of their playing season through injury. In contrast, the inside backs, who are generally involved in fewer high speed impacts, missed only 7% of their season. This finding suggests that, as the injury rates did not differ between positional groups, the injuries sustained by the midfield backs were, on average, more severe and kept them out of play for longer periods.

Previous injury

Beginning the season with injury was identified as a significant risk factor for both the incidence of injury and time lost during the season. The first of these findings is consistent with previous research.[11 12] Having been injured the previous season did not significantly elevate the risk of injury during the season if the player entered the next season injury free. These findings emphasise the importance of full rehabilitation from injury before players are permitted to take the field again after sustaining an injury.

BASIC AND LIFESTYLE FACTORS

Although an association was observed between cigarette smoking status and IR in the univariate analysis, neither this nor any of the other basic or lifestyle factors were found to be independently associated with IR in the multivariate analysis. Smoking was found to increase PM, with both ex-smokers and current smokers being at increased risk. It may be that recovery time from injury is longer for smokers and ex-smokers. Alternatively, smoking may be related to players' dedication to the sport, with more highly committed athletes foregoing cigarettes. The more dedicated players are also likely to return to play as quickly as possible.

There was some suggestion of a U shaped relation between hours a week spent in strenuous physical activity and PM, but the association was not significant. Players who were involved in very high levels of strenuous activity (more than 39 hours a week) before the season missed a greater proportion of the season than players who were less active. A similar pattern was observed for IR, although the association was not significant. This finding is in contrast with a previous finding that, for army recruits, lower levels of physical activity before entering the army were associated with a higher risk of injury during basic training.[12] It may be that the large amount of strenuous physical activity reported by the players in the current study contributed to an "over trained" state, in which players' recovery from injury was adversely affected. Over training was one explanation offered for a higher level of recurrent injury observed in professional players during the early part of the season in a recent study of Scottish rugby players.[36] This issue warrants further research to examine whether the same pattern is apparent in other populations of sports people.

ANTHROPOMETRY AND PHYSICAL PERFORMANCE

Players whose BMI was greater than 26.5 sustained a higher rate of injuries than those whose BMI was less than 23 when the IRs between the groups were examined in the univariate analysis. This is consistent with a previous examination of the influence of self reported BMI on rugby injury.[37] That study found that players who reported injuries had an age adjusted mean BMI of 25.4 compared with an age adjusted mean BMI of 24.6 for players who were not injured. In a study of army recruits, a bimodal association between BMI and injury was obtained, with those having high and low BMIs being at greater risk of injury.[13] No such pattern was found in the present study, and the above association did not persist in the multivariate model. Although BMI was not significantly associated with PM in the univariate analysis, a significant association was obtained in the multivariate analysis. It appears that players who are more frail (BMI<23) are at increased risk of losing time during the season because of injury when other risk factors are controlled for. In a previous report on data from the RIPP, BMI, as a measure of relative physical "robustness", was shown to be related to grade.[28] It is not surprising therefore that players with higher BMI reported a higher injury incidence. Overall, it appears that players with a high BMI may sustain a higher IR than players with a low BMI, yet still not miss as much of their season as a result of the injuries they sustain.

Although there were associations between some of the physical performance measures and the outcome variables, there did not appear to be strong linear trends. Of the physical performance measures, the 30 m sprint from a standing start was the only variable that had a significant univariate relation to IR. The only significant univariate result for PM was for push ups. Neither the aerobic shuttle test nor the weekly amount of off season endurance training showed significant univariate relations to IR or PM. Both the aerobic and anaerobic shuttle tests and push ups were associated with PM in the multivariate model. The patterns of association, however, were not linear, which makes interpretation difficult. Research on army recruits has found that those who have lower aerobic fitness have higher risk of injury.[12] No similar pattern was found here. These findings support to some extent previous findings[38] that superior fitness, skill, and experience do not ameliorate the risk of sustaining injuries at higher levels of play.

Although there may be a relation between fitness and certain types of injury—for example, muscle strains and tears[13]—most injuries sustained by players in this cohort were associated with tackles. It is likely that despite physical conditioning, injuries will continue to occur because of the violent impacts of tackles and the minimal amount of protective equipment players are permitted to wear. Reducing the risk of injury in tackles may come through a variety of measures including changes in technique, refereeing, rules, and protective equipment, but, before this can happen, further research on the risk factors for tackle injuries is needed.[39 40]

A possible explanation for the lack of association between the physical performance measures and injury may be that the physical performance measures used in this study did not adequately assess the fitness requirements of rugby. Rugby is an intermittent high intensity sport, with a unique blend of aerobic, anaerobic, and strength requirements.[41] Although the physical performance measures used are valid indicators of a given aspect of performance, they may not have measured the combination of physical fitness attributes required of players. Furthermore, within the sport, the various playing positions have distinct roles, and players occupying a role generally have a stereotypical set of anthropometric and physical performance characteristics.[28 29] Thus fitness tests specific to the demands of the given positions may need to be developed if the relations between fitness and player injury are to be further studied. One of the limitations of this study was that the flexibility of the players was not assessed preseason, so that associations between flexibility and injury outcomes could not be examined. Another aspect of physical conditioning that has not been examined with respect to injury risk for rugby players is the amount of physical impact drills and training players are exposed to before starting their rugby season. Anecdotally, players and coaches often refer to "match fitness", with the implication that this is an aspect of fitness not achieved through traditional rugby training methods. Part of this match fitness may be physical conditioning to the impacts with other players and the playing surface that players are exposed to during games. Further study is required to determine whether players who are adequately conditioned for physical impacts at the beginning of the season are at less risk of sustaining injuries through the early part of the season, when the injury rate has been shown to be higher.[14]

INJURY OUTCOME VARIABLES

The primary purpose of this paper was to document risk factors associated with rugby injury, as measured by two outcome variables: injury incidence rate and proportion of season missed. Most previous research has used injury rate as the outcome variable.[11 12 23] IR measures injuries per unit of exposure. It does not, however, take into account the effect of injury on subsequent participation. For example, if the scheduled season consists of 20 games, one player may sustain one serious injury in the fourth game, which excludes him from play for the remainder of the season. He has then sustained one injury (number) and has an injury rate of one injury in four games. Another player may sustain ten minor injuries through the season, none of which have a substantial effect on his ability to participate. Thus he reports ten injuries in 20 games (twice the rate of the previous player). In terms of impact of injury on their seasons, the first player has obviously fared worse, but this is not conveyed by comparison of their injury rates.

One of the strengths of this study was the use of PM as a complementary outcome variable to IR. PM does have its limitations, with injuries that occur early in the season likely to cause a greater proportion of the season to be missed than those that occur towards the end of the season. For instance, players who sustain an injury in the last game of the season will not miss any weeks of play, whereas if they had sustained the same injury at the beginning of the season they may well have. Hence, there is some censoring of the time missed depending on when in the season the injury occurs. In addition, using proportion of season missed does not readily allow modelling of concurrent risk factors through the season, the level of which may vary from week to week. These include factors such as playing out of position and use of protective equipment for a given game.

SUMMARY AND CONCLUSIONS

This study examined risk factors for injury and playing time lost, as measured by IR and PM. Different sets of risk factors were associated with each of these outcomes. Significant univariate associations with IR were observed for grade, age, and previous injury experience, BMI, and 30 m sprint time from a 5 m running start. After possible confounding factors had been controlled for, grade and previous injury emerged as independent risk factors. Univariate associations with PM were observed for: playing position, strenuous physical activity, cigarette smoking status, alcohol use, previous injury experience, and vertical jump. After possible confounding factors had been controlled for, playing position, BMI, strenuous physical activity, previous injury, and cigarette smoking status emerged as independent risk factors.

The results of the analysis of previous injury indicate that players who entered the season carrying an injury placed themselves at higher risk of both missing play and sustaining a higher injury incidence rate through the following season. Thus returning to play before full recovery from injury may also place players who were otherwise fit at a higher risk of further injury. To reduce their risk of sustaining injuries and missing playing time, players should enter the rugby season injury free. If interventions to reduce the impact of injury are undertaken on the basis of risk factors identified through studies that use IR as the outcome variable, it is important to remain aware that factors associated with the impact of injuries on players' participation through the season may not necessarily be identified, as the risk factors associated with the IR and the PM may differ. Comparison of the results for each of the outcome variables may help to elucidate the nature and severity of injury more effectively than either would be able to separately.

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APPENDIX 2

INJURY PREVENTION IN NEW ZEALAND RUGBY –

SUCCESSES AND CHALLENGES

PUBLISHED IN GAMEPLAN RUGBY, THE NZRU COACHING JOURNAL

AUGUST, 2003

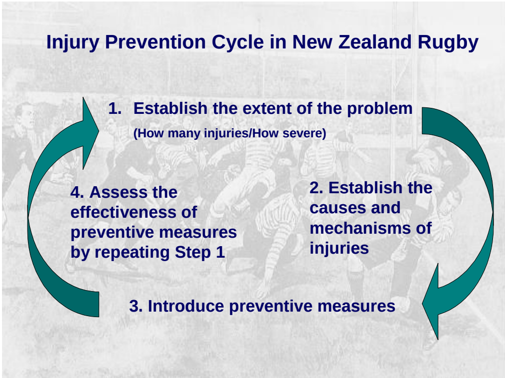
KENNETH L QUARRIE

Injury Prevention in New Zealand Rugby - Successes and Challenges

At a recent planning meeting for injury prevention (IP) over the next 3-5 years, a comment was passed that many New Zealand coaches were unaware of either the overall approach to IP, or the successes that had been achieved over the past 10 years in this country. The person that mentioned this, who happens to be the editor of this magazine, suggested I write an article outlining the strategy behind what is being done, and what has been accomplished to date.

The Injury Prevention Cycle

The basic approach to IP in New Zealand rugby is the cycle proposed by Willem van Mechelen in 1992, which is shown below. To find out both how widespread a particular injury issue is, and what factors are contributing to it, research into injuries and factors associated with them is required. On the basis of what is discovered from the science, and in consultation with those who have an interest in the sport, injury prevention measures are launched. The success or otherwise of these is monitored by further research - and so the cycle goes.



Why Injury Prevention in Rugby?

To understand the strategy behind current IP initiatives it helps to have some background as to why IP is part of the New Zealand rugby landscape at all. One of the questions that has been asked of me a number of times since I started working with the New Zealand Rugby Union is 'why bother with injury prevention in rugby?'. The logic behind questions such as this seems to be that because of laws, nature and history of rugby, injuries are an unavoidable part of the game.

Up to a certain point, this is true. Tackles, scrums, rucks and mauls are integral parts of rugby, and are also associated with most of the injuries that occur in the sport. A game without tackles, scrums, rucks and mauls would no longer be 'rugby' but something else. As with most things, however, there is more to the picture than meets the eye. Certain types of tackles, and certain techniques in scrummaging, can put players at higher risk of injury.
Through the 1990's and the first three years of this century, knowledge concerning rugby injuries has increased rapidly.

Step1. Establishing the extent of rugby injuries

Two of the main drivers for national injury prevention initiatives in New Zealand rugby were:

1. Injuries due to participation in the sport that resulted in death or permanent disablement (e.g. spinal injuries and some head (brain) injuries). There was a worldwide increase in the numbers of these injuries - especially spinal injuries occurring in scrums - during the 1970's and 1980's. These injuries have a catastrophic effect on individuals and their families, and also deter people from taking up or continuing with the sport.
2. The finding of ACC in the late 1980's that rugby cost the taxpayer over $20 million dollars per year in new and ongoing entitlement claims. There were, on average, 2 deaths, 1500 hospital admissions, and 20,000 Accident and Emergency consultations per year as a result of rugby.

These factors, among others, lead to the setting up of a study in Dunedin called the Rugby Injury and Performance Project (RIPP) in 1993. The purpose of this was to address the first two issues in the IP cycle: how many injuries are occurring given how many players take part in the sport, and how much time they spend playing and practicing, and the identification of factors that cause injuries, or put people at higher risk. The people involved in RIPP included doctors, researchers, rugby administrators, statisticians, fitness trainers and, of course, the players.

RIPP followed 356 rugby players from various grades (Senior Men and Women through to colts, schoolboys and schoolgirls) throughout an entire season. Information about factors that may have been associated with variations in risk of injury was collected at the start of the season, and then information was collected on the players by weekly telephone interviews. This included finding out about the participation of players in matches, practices and other training, and the sites, type and severity of any injuries they sustained. Because information was collected from all of the players, comparisons could be made between the characteristics of those who were injured and those who were not.

Once all of the information had been collected, the scientists set about describing the number (and rate) , type and severity of injuries that had occurred, and the factors that seemed to put players at higher or lower risk of injury. Some of the findings confirmed opinions that were widely held by rugby people prior to the study, whereas some forced people to reappraise why they held certain beliefs.

Among the results were:

- 47% of injuries were sprains and strains
- 40% of injuries occurred in tackles
- 13% were reported by players to be the result of foul play
- 85% of players wore mouthguards in games

Step 2 - Establish the causes and mechanisms of the injuries

No single study is likely to provide all the answers to a specific research question, and so it was with RIPP. The design of RIPP, however, allowed more complex analyses of factors associated with rugby injuries than had been the case with studies conducted in the past. Some of the findings were:

- Players in higher grades had higher rates of injury
- Males had higher rates of injury than females
- Players who self-reported that they were injured at the preseason assessment were at higher risk of both sustaining injuries and missing play as a result than players who entered the season injury free.
- Cigarette smokers tended to miss more play due to injuries than non-smokers
- Particularly thin players (those with a body mass index of less than 23) tended to miss more play than their more robust counterparts

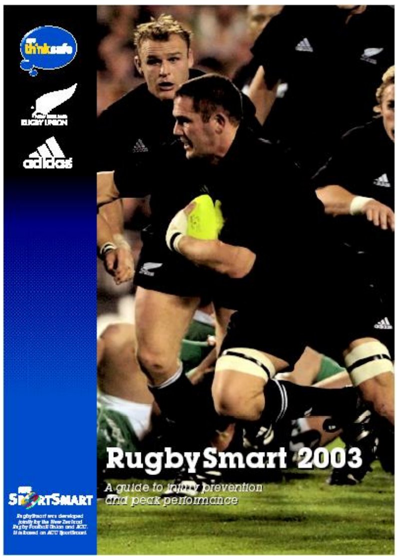
The findings of studies such as this are probabilistic - that is, they look at the risk across the population and say - on average, what factors are associated with higher risk of injury. Pointing out exceptions (of which there are bound to be some), often confuses people when they try to interpret research as it relates to their own experiences. Thus while male players had, on average, higher rates of injury than females, it doesn't mean that a particular female may not have had more injuries than a particular male.

Step 3 - Introduce Preventive Measures

Based partly on the findings of RIPP, and partly on consultation with rugby participants, a series of recommendations for reducing injuries to New Zealand players was developed. These were presented to the New Zealand Rugby Union and ACC in a document called 'Tackling Rugby Injury'. The recommendations included:

- Injury prevention training for coaches
- Mouthguards for all players
- Further examination of ways to reduce tackle injuries
- Monitoring of foul play

In 1996, a large number of spinal injuries in the early part of the season prompted an emergency meeting between Richie Guy, then Chairman of the New Zealand Rugby Union, and a number of medical and scientific experts. As a result of this, compulsory injury prevention courses for coaches were launched.



These courses focussed on safe techniques in contact situations, adequate physical preparation to cope with the demands of play, and appropriate management of injuries that did occur. From 2001 onward, the courses have used the ACC SportSmart 10 point plan for sports injury prevention, and have been called 'RugbySmart. It is a requirement set out by the NZRU Board that all coaches, assistant coaches, and referees of all grades of tackle rugby attend RugbySmart annually. In 2003, for the first time, the option was provided for coaches and referees who had attended RugbySmart in the previous year to demonstrate their knowledge of safe techniques through sitting on 'online test'. About 8% of coaches and referees sat and passed the test. The test was well received by most of those coaches and referees who attempted it. There were a number of technical difficulties with setting up the test so that all those who were eligible could take it, but the NZRU hopes to have this functioning smoothly for the 2004 season.

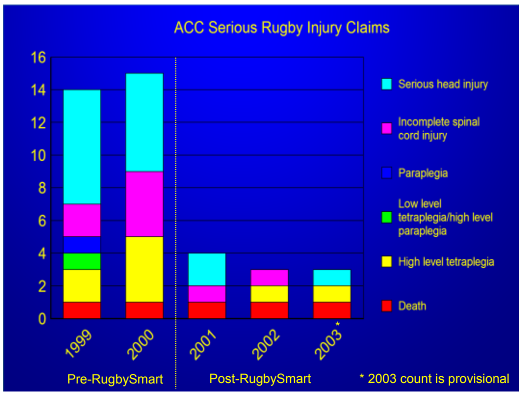
Player based courses, such as the Front Row Factory, and compulsory safety courses for school girls entering the sport at high school level seem to have had a positive effect in decreasing the number of the most serious injuries in scrums.

Step 4 - Assess the effectiveness of the Injury Prevention Strategies

So - have these initiatives worked? I will outline the results in several areas.

Serious Injuries

Overall, there seems to have been a positive effect. According to ACC figures, the number of the most serious injuries has decreased since 1999. The number of these injuries tends to vary widely from year, to year, so there is no room for complacency.



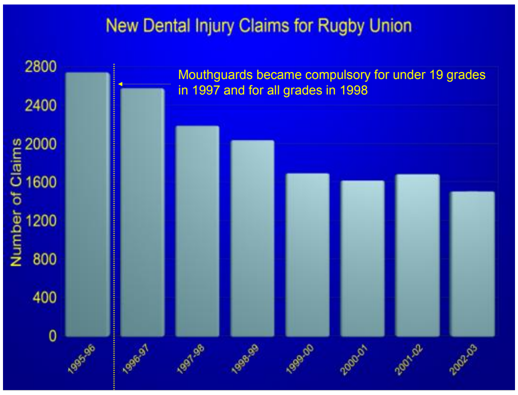
Until the mid 1990's, many rugby participants considered spinal injuries to be the result of 'bad luck'. There was a lack of understanding of the ways in which forces applied to the body could result in damage to the spinal cord. Information about 'how' such injuries occur has presented to coaches and players, and while images of necks fracturing do not make for pleasant viewing, they certainly get the message across about the techniques players should adopt to avoid the most serious injuries that are seen in rugby.

Changes to the laws with respect to the control of scrum engagements, and the number of trained front row players all seem to have had an effect in terms of decreasing the number of spinal injuries resulting from scrums over the past eight years. The proportion of spinal injuries occurring in the tackle situation has increased over the same period. This is probably related to an increase in the number of tackles per game, and a change in the typical type of tackles. As noted in the last issue of GamePlan, there has been a trend towards high, front-on tackles at the higher levels of the sport, with a 'copy-cat' effect filtering through the grades. Because such 'offensive defence' can provide an advantage to the tackling team in terms of their chances of either recovering the ball or disrupting the opponents ball, coaches have tended to move towards it. The challenge is for coaches to develop sufficient levels of skill in contact among their players that they can both execute and receive such tackles as safely as possible. It is also important that players do not attempt tackles such as this before they are competent – both physically and with respect to their ability to judge time and distance and are well practiced in the training environment before trying to put them into effect during matches.

Dental Injuries

Mouthguards were made compulsory in New Zealand for Under 19 players in 1997 and for players at all grades in 1998. The number of 1998 dental injury entitlement claims has decreased by approximately 40% since 1996 – due in part to this change. New Zealand currently has a stronger policy on mouthguards than most countries (IRB laws state that mouthguards may be worn). The New Zealand position was further strengthened for the 2003 season by a domestic safety law variation that allows referees to insist that players who are not wearing a mouthguard (in their mouth!) have to leave the field and obtain one. If they are unable to get one, they may only be replaced after ten minutes have elapsed.

It will be interesting to examine whether the increased wearing of mouthguards that comes about as a result of this Domestic Safety Law results in further reductions to the number of dental injuries in rugby.



Summary

The challenge for injury prevention in rugby is to implement strategies that are effective in reducing the number and severity of injuries - especially those that result can permanent disability or death - while not changing the essential nature of the game as a physical contact sport.

However, with the emerging research, it is evident that many of the strategies that minimise injury risk are also those which give a team the best chance of being successful on the field. For example, players who do not fully rehabilitate an injury tend to end up missing more play (and sustaining more injuries) than they would if they took the time to get the injury properly healed in the first place.

From the coaches' perspective letting players rehabilitate properly means that they have access to their players for as many games as possible. The challenge for coaches is to increase the skill level of all the players in their squad so that they reduce the impact of having one of their front-line players unavailable for a period. In close competitions, it is often the team with the most 'depth' - or skill across the squad that emerges victorious.

Injury prevention in rugby is a cooperative effort among a large number of groups. The NZRU, Provincial Unions, clubs, schools and ACC all have a part to play. The goal of injury prevention is not to 'wrap players in cotton wool', but to ensure that they can maximise the enjoyment of their playing time while minimising the annoyance, cost (and pain) of injuries.

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APPENDIX 3

CHANGES IN GAME PATTERNS IN RUGBY AND

PHYSICAL ATTRIBUTES OF PLAYERS

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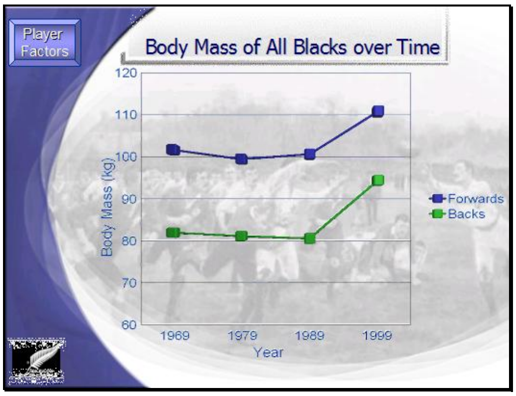
KENNETH L QUARRIE

Changes in game patterns in rugby and physical attributes of players

Imagine, for a moment, that the All Blacks are running onto the field for a test match. People throughout New Zealand are tuned into only one thing…the performance of the All Blacks over the next 80 minutes. The announcer's voice is fraught with emotion. The crowd atmosphere is electric. The commentator describes the All Blacks forwards as they run onto the field…"and here comes Newton, the giant of the All Blacks pack. Weighing in at 95.4 kg this season, he is over 10 kg heavier than the average All Blacks forward"… Hold on, you might think, something is wrong with this picture. The heaviest All Black weighing in at 95 kg? The average All Black forward weighing 85 kg? What planet are you on?

While I have converted the weights from 'stones and pounds' to kilos, if you were an All Blacks supporter tuned to the radio during the 1905 tour of the British Isles (I'm not even sure that rugby games were reported via radio in 1905!), that is exactly what you might have heard. The change the size of rugby players is dramatic. In fact, a paper by some Australian scientists in 2000 indicates that the change in rugby player size is much greater than the typical size increase in the overall population, which means that a smaller proportion of people in the community today are as big as the typical test match player from the corresponding period in the past. A browse through the New Zealand Rugby Almanac over the years reveals that the change in player weight has accelerated since the late 1980's. The average weight of All Black forwards in 1989 was just over 100 kg, as it had been since the late 1960's, whereas in 2002 it was almost 111 kg. The change in the weight of backs has been even more striking than that of the forwards, with the average weight of All Blacks backs moving from about 80 kg to 94 kg over the decade from 1989 to 1999. John Kirwan, when he burst onto the scene in the mid 1980's, was a big back (weighing in at around 92 kg). In one of his last All Black trials he marked a young Jonah Lomu, who (at that stage) was weighing in at well over 110 kg.



While these changes are interesting (and are evident for those who watch games from years gone by on Sky's Rugby Channel), it is the relationship between factors such as player size to the structure of the game itself that starts to reveal fascinating patterns.

When push comes to shove - changes in the rugby union scrum

One of the finest thinkers in New Zealand rugby, the late J.J. Stewart, published a book entitled "Rugby - Developments in the Field of Play" in which he outlined changes in the game from the late 19th through the 20th Century. This is a great book for any coach wishing to steal a march on their peers by tracing the history of the game, and looking towards where it is likely to develop in the future.

With the amount of rugby on television in the modern era, it is easy to lose sight of longer term trends in the game. Changes that are subtle and generally go unnoticed when they first emerge can result in major changes to the game in the longer term. In the rest of this article, I want to focus on the scrum and tackle, and how developments in these aspects of the game have impacted on both performance and injuries in New Zealand rugby.

The term 'scrimmage' from which both the 'set scrum' and 'loose scrum' (or ruck) developed was originally a group contest for the ball, which often consisted of one team trying to kick or 'hack' the ball forward past the opposition. American Football (Gridiron) descended directly from rugby, and Timothy Noakes and Morne Du Plessis in their book 'Rugby without Risk' provide an excellent account of how American Football Administrators developed their own version of the 'scrimmage', and how President Roosevelt intervened to increase the safety of the sport after calls were made to ban it. The resulting changes included the elimination of 'massed play', the introduction of the forward pass, and the development of protective equipment. This emphasis on safety continued when the sport agreed to put in place injury surveillance systems to track changes in injury trends.

Within rugby, the scrum has not always been the contest for physical dominance over the opposition that it is today. Initially, it was a means of restarting play after minor rule infringements, with both teams having about the same chance of winning the ball after it was put into the scrum. Various scrum formations have been used in rugby (e.g. 2-3-2 and 3-2-3), but even after the 3-4-1 formation was adopted the scrum remained a relatively even contest for possession for a number of years. J.J. Stewart provides an intriguing narrative of how the lawmakers in the game tried (unsuccessfully) to combat the tactics adopted by the 1949 Springbok team which provided them with an almost certain chance of obtaining possession after their own scrum-half fed the ball into the scrum. According to J.J. it was at this stage that the terms 'loose head' and 'tight head' entered the rugby dictionary.

The next big change to the scrum occurred in the early 1960's. Up to that point, loose forwards did not really push in the scrum, but were allowed to follow the ball through the opposition scrum, pouncing on the halfback as it emerged, and getting a flying start towards the first five eighths. To provide the halfback and first five with more time to clear the ball, a law change was put in place that required that loose forwards had to stay bound to the scrum, or retreat behind the last foot in their own scrum. As with many law changes, the intention of the law makers and the actual effect on the game ended up being quite different things. Coaches soon learnt to use this law change to their best advantage. Whereas very quick ball from the scrum had been an advantage, this law provided an edge to teams that brought the ball slowly back through the scrum. Over the next decade, the dynamics of the scrum changed dramatically. Scrums became a sustained pushing contest, with loose forwards expected to push. The increased requirement for pushing force led to developments such as scrum machines and 'pushover' tries.

"...in the course of a severe scrimmage a young gentleman named Lomax got down, with his head bent under his chest, and in this position was trampled on by many of the players. He was picked up insensible, and, with the exception of short intervals of consciousness, he has remained so until the present time... If he survives, (which is still doubtful!), it is feared he will be a cripple for life."
The Times, 27 November, 1869.

Effects of Power Scrummaging

As the quote above indicates, serious spinal injuries have been associated with rugby for over 100 years. In terms of the number of players and the physical nature of the sport, they have always been a relatively rare occurrence.

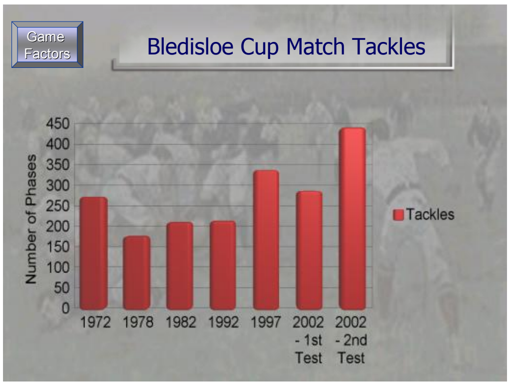
However, 'power scrummaging', as it developed through the rugby playing nations brought with it a tragic side effect. The number of spinal injuries associated with scrums increased markedly throughout the 1970's, and resulted in further law changes to the scrum designed to reduce both the danger of the front rows collapsing as the packs engaged, the force generated at engagement. and the duration of scrums (by decreasing the distance over which scrums could push).

Further changes to the procedures for scrum engagement were instituted in the mid 1990's. These changes gave the control of the scrum engagement to the referee, who called 'crouch, hold, engage'.

This appears to have decreased the number of injuries that occur during scrum impact, when one of the teams is not ready to engage. The proportion of rugby related spinal injuries resulting in paralysis from scrums has dropped over the past decade and the proportion occurring in the tackle situation has increased.

Research is required into the long term effects of power scrummaging and the use of scrum machines on the structure of spinal column, and whether any resulting structural changes place players at higher risk of paralysing spinal injuries.

'The big hit' – Changes in the nature of tackles



The increased demand for strength in the contact phases of the sport, due to a game based on retention of possession, has also led to greater forces being applied in those contact situations.

An interesting exercise was carried out by the Analysport Coding team at the aIOR. They coded the first test from selected Bledisloe Cup Match Series from 1972 to 2002. Tackles were coded in terms of their number, direction and height.

A 62% increase in the average number of tackles per test was observed after the game switched to professionalism in 1996. A further analysis which examined the number of high (between the shoulders and the bottom of the rib cage) front-on tackles revealed an increase in this type of tackle of around 128%.

Because these tackles require a high degree of skill and timing ability, it is doubly important that the basics of safety in the tackle are taught to players by coaches from their entry in the sport. The common principles of safety in contact, which include instructing the player to keep the head up, eyes open, and back flat in contact can begin in grades such as Small Black Rugby even before tackles become part of the game (i.e. during 'touches'.

With the rapidly changing structure of the game, and the demographics of the playing population in mind, a comment from J.J. may be an apt way to end the article:

"If this development progresses, as seems not unlikely, towards a game wherein the contests for ball possession are intensely physical and sustained – power scrummage; time extended mauls; crash tackling; rolling mauls; player pile-ups on the ground; and where the object of carrying the ball and running is not to elude opponents but to run into them with contact aimed at taking them out of the game for a period – then we are on track for producing a game which can only be played by a few at whatever the level…

…As rugby moves into the next century, however, it must carefully guard its ethos and tradition and avoid the likelihood of its becoming a game for big men only; and at lower grades and schoolboy grades of becoming a game for big, strong, early maturing boys only."

Dealing appropriately with the concerns raised by J.J. remains an issue that is at front of mind for many of those charged with the responsibility of administering our national game.

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APPENDIX 4

WHERE TO IN THE DECADE AHEAD?

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KENNETH L QUARRIE

WHERE TO IN THE DECADE AHEAD?

Prediction is extremely difficult. Especially about the future.
- Niels Bohr (1885–1962) Danish physicist.

As I write this, it is the eve of the 2003 Rugby World Cup. With the above quote in mind, I thought it might be worthwhile to reflect on the 'state of the game' and take part in some crystal ball gazing regarding how our game may develop as it matures as a professional sport over the next decade. Some of the predictions will be self-evident to anyone who follows rugby, but hopefully some may stimulate thought and debate about the directions rugby may take in the future.

The focus will be mainly on how some of the factors already present may work to influence both player performance and injury patterns. These are my thoughts only, and should not be construed as being the position of the New Zealand Rugby Union on any of the issues raised. In some cases I have deliberately tried to raise issues intended to provoke debate. In most cases I will be wrong – but then, that is the nature of making predictions! I look forward to any feedback (positive or negative) that this article may produce.

Rugby as a dynamic system

Rugby can be thought of as a dynamic and evolving system, in which widely varying patterns occur within set boundaries [1]. In this way it is like other complex phenomena, such as weather patterns and stock market prices. Among the features that are shared by these types of systems is that they are very sensitive to initial conditions, and it is very difficult to produce predictions that are accurate in the long term.

Another typical feature is that they exhibit 'emergent' properties – i.e. the whole is greater than the sum of the parts. This means that trying to understand the overall system by breaking it down into its constituent elements (the reductionist methodologies typically used by scientists in the 20th century) may not be particularly fruitful [2]. Dynamic systems are not completely random, meaning that they are more predictable than next weeks lotto numbers, but nor are they simple linear systems in which a given stimulus will always result in the same outcome.

One of the features of rugby that contributes to its development is that information that is generated by the sport 'feeds back' directly into the sport and is integrated into the behaviours of the stakeholders in the future. Thus a coach who generates an innovative and successful style of play with a single team may cause large changes in the way other coaches approach the sport. Whether other coaches (and the style their teams play) will in fact change is difficult to predict. For example, other coaches may imitate aspects of the style of play developed by the first coach; they may develop new strategies of their own to counter the style developed given their perceptions of their own team's strengths and weaknesses; or they may choose to ignore the new style and continue to focus on what they were already doing.

Some of the factors that influence playing patterns and injury risk

The laws of the game…

The structure and patterns of play that occur in rugby are implicitly defined within the laws of the game [3]. The laws do not, however completely describe the patterns of activity that are typical of the sport – these patterns are an emergent property that develop from the application of the laws, but are not explicitly stated within them.

One of the implications of this is that when laws are made or altered the intentions of the lawmakers and the impact of the laws on how the game is played do not necessarily match up. Coaches and players tend to search for the interpretation of a particular law that will result in them obtaining a competitive advantage.

Compared to team sports such as soccer and field hockey, rugby as a sport has a history of frequent modifications to the laws of the game. It is not beyond the bounds of possibility that there will be further changes over the next five to 10 years that result in major alterations to the structure of the sport in the long term,

…and the laws of the land.

Participants in contact sports voluntarily assume a level of risk. In legal terms this is called 'volenti non fit iniuria' [4]. This does not mean that the law ceases to apply at all – if a player deliberately injured another they could potentially be charged if the police decided that the circumstances warranted a prosecution. Likewise, if an administrator was willfully negligent through an act or failure to act that resulted in a person being injured as a result, there is scope within the law for a remedy to be sought. The ACC legislation precludes damages for personal injury being sought, but in extreme cases actions could be taken by the injured party for exemplary damages (under common law), or the police may consider launching a criminal investigation.

Within New Zealand, a player was convicted in 2003 for assaulting a referee, and it is possible that a player could be prosecuted for assaulting another player, especially if they were acting outside the laws of the game. Recent cases brought by the police against the organisers of sports events where spectators or participants have been injured also highlight the fact that although the laws of rugby are those that receive the most attention during matches, the laws of the land do not cease to exist while a match takes place. The NZRU, Provincial Unions and ACC have developed a Community Rugby Health and Safety Checklist.

This is designed to help clubs and schools ensure that they are providing a safe environment for rugby, and will help to minimise the risk that individuals or organisations that host rugby matches will run afoul of the law.

Internationally it appears that sports participants are becoming increasingly litigious, and actions have been taken by players against referees, players and administrators for injuries sustained on the field of play.

Stakeholders and the Development of Rugby:

The sport of rugby is subject to evolutionary pressures that come from the interests of rugby's stakeholders. Stakeholders are all those who have an interest in rugby – and they vary in their world views of what is desirable for rugby, and what rugby should provide them. This is the case even within stakeholder groups – not all members of a group see things the same way. The stakeholders also vary in their ability to directly influence the future development of the sport. The picture below shows some of the stakeholders that influence both the way the rugby is played and the subsequent injury patterns.

Broadcasters and Competing Sports Products:

It is no secret that the single biggest provider of funds to rugby since the sport became professional has been those who purchased the television broadcast rights to the sport.

Broadcasters want a game that excites fans, because the greater the fan base, the more sponsors and advertisers will be willing to pay to promote their products in conjunction with rugby. One of the common patterns that has emerged with respect to most sports that are televised widely in America has been the alteration of game structures so that they:

- Are predictable in terms of total event time
- Have frequent and regular breaks in play to allow commercials to be broadcast

An example of a change that broadcasters have helped instigate are the introduction of the tie-breaker in tennis, (to decrease the length of sets so that programming schedules would be less prone to disruption by long matches).

So, gazing into my crystal ball, I would not be surprised if there was a move towards playing rugby in four quarters, which would allow for extra commercial breaks. Before the purists among the readers cry that this won't happen, I would point out that it is only since the sport became professional that the typical length of the half-time break has changed from five to 10 minutes in high level matches. This was not done because players all of a sudden needed 10 minutes rather than five to recover from their exertions in the first half, it was done because it allowed for more commercials to be shown. American Football was originally played in halves rather than quarters, and in both American Football and Basketball the introduction of 'timeouts' was also driven primarily by broadcasters.

Recently there have been claims that a primary reason that soccer has not made the 'big time' in America is that the two 45 minute halves do not allow sufficient advertising content through a match to make the sport attractive to broadcasters when compared to the sports that are already considered 'prime time' in the US [5].

The time some players spend taking conversions and penalties may also come under scrutiny because they take away from the time the ball spends 'in the action'. The amount of time kickers are permitted to take on each kick has already been capped. Place kicks used to be used for kick offs whenever a try was converted, and could even be used to kick the ball into touch from a penalty. Kick-offs have already changed to drop kicks. Conversion attempts in sevens rugby are also required to be drop kicks. Could it be the end of the incredibly precise place kicking 'machine' is in sight? This will probably be opposed most strongly by those stakeholders whose sides have the best kickers…

One of the other changes that may take place at the request of broadcasters is an alteration to the way injuries are dealt with on the field. In professional soccer players are moved off the field so that play can continue as soon as it is established that they have not sustained an injury that may result in permanent disablement. There has been a trend towards an increase in the time each match takes since rugby turned professional – partly due to increasing time spent treating injuries on the field. The disruption this causes to broadcasting schedules has already been noted by the television industry.

Preliminary analyses of the Super 12 indicate that the typical number of injuries treated on field per match varies widely across the teams, indicating that they either have different criteria for having injuries assessed, or they use the time taken to have a rest and formulate tactics…

Since rugby became professional, it is viewed by broadcasters, other media and sponsors as an entertainment product, and as such competes with both other sports and other modes of entertainment for income. The future success of rugby depends strongly on its ability to produce a product that captures the interest of new television viewers worldwide. Look for:

- More interactive viewing experiences in which spectators can call up virtual replays of events from whatever perspective they choose.
- More interactive viewing experiences in which spectators can call up virtual replays of events from whatever perspective they choose.
- Greater depth of statistical analysis presented to viewers in real-time during matches Sponsors.

The relationship between sponsors and sports organisations is generally symbiotic – the sport receives income to enable it to meet its objectives, and the sponsor increases product sales via targeted marketing to those who are interested in sport. The particular aspects of the sport that a given sponsor will choose to be associated with depends heavily on the segment of the market they are targeting.

In some cases the views of the sponsor will compete or conflict with those of other stakeholders in the game. For example, the recent series of Steinlager adverts featuring Wayne Shelford playing on after sustaining an injury were produced by Lion Breweries to highlight the commitment exhibited by All Blacks in years past. In recent years research has shown that playing injured substantially increases the risk of future injury [6]. In addition, one of the most obvious effects of injury is an inability to perform to the same level that a player was capable of before they were injured. While Shelford's actions may have been considered 'heroic' in the era in which they occurred, today playing on after sustaining such injuries would be considered counterproductive, because it decreases the ability of the team to play to its potential.

Are the All Blacks of today any less committed than in Shelford's time? No, but with access to better information than was available in the past coaches and players realise that to maximise their chances of winning they need the players on the field to be fit.

My prediction is that players will become increasingly more committed as athletes as the competition for places in the top teams increases. Players are likely to go the extra distance in terms of both preparation and recovery, because they know that their competition is doing exactly that. The heavy alcohol use that has traditionally been associated with rugby [7, 8] is likely to decrease – at least at the highest levels of the sport, because of the negative impact of alcohol on post-match recovery from the muscle damage incurred during matches.
Fans/Supporters

This is a group in which the views of various subsections of the whole vary widely. To take injury as an example, there is an almost universal belief among fans and supporters that players participating in the sport should not be permanently disabled or killed through playing rugby.

There is no doubt that the physical contact elements of rugby are those that are most strongly associated with injury risk. The extent to which physical contact is seen as a desirable element in the sport, however, depends strongly on the perspective of the particular supporter – and will sometimes vary with circumstances even within a given person. For example, the same person who celebrates a 'big hit' made by an All Black playing against England may view the same type of tackle in an entirely different light if it occurs to their child when playing junior rugby.

The approach taken within injury prevention in rugby has been to minimise the chances of players being seriously injured while retaining the essential nature of rugby as a contact sport. This has been done by educating participants to be aware of the elements of physical contact that are particularly risky. In addition, there is now a progressive introduction into contact within rugby from the ages of five to thirteen. Coaches, referees and players are provided with guidance as to how to instruct players in effective and safe technique in the physical aspects of rugby via NZRU and Provincial Union education initiatives, including RugbySmart.
Administrators

Those controlling the game (the IRB, National Unions) are placed in the same situation as other business people – they need to maximise the value of their product in the marketplace. To do this requires evaluating the needs of the various stakeholders and meeting them to the extent possible. The development of rugby as a truly global sport will depend heavily on the ability of the administrators to meet the expectations of stakeholders effectively.

Players

It used to be said that rugby was a sport for all body shapes. While this may still be true among the lower levels of the sport, it is certainly not the case among those playing at top levels. While this was covered in a GamePlan article recently [9], it is interesting to speculate about what may happen to player body sizes and shapes at the professional level of the sport. If rugby were to move towards play in quarters or unlimited substitutes were allowed, the size of the players would, on average, increase. Rugby players are large at present, because the muscle mass they carry helps them cope with the high impact nature of the sport. Even so, the heaviest players in rugby (typically the props and locks) are seldom over 120 kg (this is big!). This is because the aerobic demands placed on players as they move from phase to phase help to keep their weight down. Compare this with NFL linemen, who are commonly around 145kg (this is huge!), and can weigh in at over 180kg (this is gargantuan!).

The size of rugby players has been increasing faster than that of the general population for a long period [10], but looking into my crystal ball I predict:

- There will be less differentiation among the physiques of the backs (actually, I am cheating here. This prediction was made after the 1995 World Cup by Tim Noakes and Morne du Plessis. [4] . I predict that it will continue to happen). The typical physique of backs will continue to tend towards the 'loose-forward' physique of a few years ago
- The average height of the locks will continue to increase
- The average speed of professional players will continue to improve – especially in the outside backs

So, moves that result in players being able to play for less time on average will probably result in an increase in weight because it lends them an advantage during the contact phases. The changes in the physiques of the props and hookers would probably be the most noticeable – they would be likely to get bigger and faster than the other positions because of the extra demands they face during the scrum.

On the other hand, if substitutions were limited (or reduced), which I think is less likely, and the game remained in two halves, the average size of the front row forwards would be likely to stay about the same, or perhaps even decrease as the pace of the game continues to increase.

Match Analysis

Top level rugby is now intensely analysed. The breadth and depth of research designed to provide teams with a competitive edge is likely to increase rapidly over the next 10 years. Major changes to the science regarding rugby are likely to include:

- Utilisation of new computing techniques (such as those used currently to predict long term weather patterns) to examine trends in play
- Greater individual intervention with the training, dietary and recovery regimes of professional players

Using this perspective, it is easy to conceptualise the sport at varying 'levels'. For example, a single rugby match can be analysed in terms of the events during a particular match (tries, tackles, scrums, lineouts etc.). Jumping a level, analysis of a series of matches can reveal trends within the sport itself – whether the sport is becoming faster, whether there are more or fewer passes or tries or whatever compared with how things were previously. The IRB match analysis centre now does a great deal of this type of work each year. Jumping another level, analysis can be made of the factors that are contributing to changes that are apparent within the sport.

The Medical and Insurance Communities

The physical and fiscal costs of injuries in rugby have received a much greater degree of attention since the sport became professional than was the case prior to 1996. Within New Zealand, the costs of sports injury are borne primarily by the taxpayer via the ACC system. In other countries, self-insurance is often required. As alluded to above, the level of injury which is considered 'acceptable' varies widely across (and within) stakeholder groups. This tension is likely to continue – simply because the perspectives of the groups differ. As Shakespeare said 'nothing is good or bad, but thinking makes it so'.
Predictions for injury prevention are:

- Greater attention given to making evidence based law changes to prevent injuries as a result of in-depth injury analyses conducted over multiple matches/competitions
- Greater understanding of the relative risks of participating in rugby versus other sports and recreational activities
- Continuing pressure from the medical and insurance communities to rugby lawmakers to modify the tackle situation to decrease the risk of injury (e.g. mandating that a tackle must be below the line of the nipples)
- Rapid increases in the understanding and management of concussion injuries
- Studies that track the health outcomes of players after they finish their playing careers

Conclusions

As pointed out by Paul Thomas in his recent book, the changes to the game that have occurred as a result of professionalism don't suit everyone [7]. One thing that is certain to occur in the rugby context over the next five to ten years is change – at least as rapid and far reaching as anything seen to date, and probably more so.
I can only speak for myself here, but I would like to see a game that is fast and exciting, requires a high level of skill, and retains the physical element that has defined rugby since its origins. What type of sport would you like rugby to be in future?

APPENDIX 5

REFLECTIONS ON RISK, SAFETY AND PARTICIPATION IN JUNIOR RUGBY

PUBLISHED IN GAMEPLAN RUGBY, THE NZRU COACHING JOURNAL

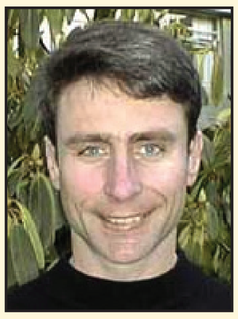
JUNE, 2004

KENNETH L QUARRIE

RugbySmart

with KEN QUARRIE

ACC SPORTSMART



KEN QUARRIE
Manager of Research and Injury Prevention, NZRU

REFLECTIONS ON RISK, SAFETY AND PARTICIPATION IN JUNIOR RUGBY

A survey was undertaken on behalf of the NZRU in 2003 to find out more about why teenagers stop playing rugby. Three hundred and fifty teenagers who were registered rugby players in 2001, but didn't register in 2002 were contacted and asked questions about their attitudes to rugby, and the reasons they chose not to play in 2002. The results of the survey indicate that the most commonly cited reasons for stopping play included work commitments (mentioned by 32% of the sample); injury (31%), and concerns about being injured (21%). Clearly either the experience of having sustained an injury or the perceived risk of suffering an injury in the future is enough to discourage a reasonable proportion of players from continuing with the sport.

But how risky is junior rugby? This is not an easy question to answer. To get an understanding of injury risk within rugby requires knowledge of not only how many injuries are occurring, but of the number of players and the amount of time they spent participating in the activity. People who study patterns of injury or illness within populations are called epidemiologists, and they typically report rates of injury against some standard measure of exposure. By comparing the rates of injuries in different activities, estimates of the relative risk associated with the particular activities can be calculated.

So – back to the question – just how risky is junior rugby? Like just about everything else, the answer is – it depends. It depends on the level of play, the size and degree of physical development of both the player and their opponents, the attitudes of parents, coaches, and players, and a whole host of other things – what the epidemiologists are fond of calling 'a complex web of interacting risk factors'. It also depends on whether you are talking about the risk of receiving bumps and bruises – the 'minor' soft-tissue injuries that make up the great proportion of all injuries that occur in the sport or the most serious injuries that can result in permanent disablement. If you are talking about minor bumps and bruises, it is likely that you will experience your fair share if you are playing rugby. A much smaller number of junior players will sustain more serious injuries – such as fractures or dislocations. A study of injuries sustained by schoolboy players in Christchurch indicated that 4% of injuries were 'serious' . Serious injuries prevented players playing for 21 days or more. And very few, if any, junior players will suffer injuries that result in long term disability. As part of my role with the NZRU I have scrutinized the research articles on spinal injuries in rugby that have appeared in the medical journals over the past thirty years. Given the number of players and the amount of rugby played, the risks of any player sustaining a serious, permanently disabling injury are very low, and among the junior grades (aged 14 and below) this risk vanishes to almost zero (I am aware of one spinal injury to a 14 year old in New Zealand over the past 30 years).

A recent comparative study of youth soccer and rugby concluded that the incidence of injury in New Zealand school teams playing soccer or rugby was 'high' . 145 soccer players and 123 rugby players were followed through a season. The patterns of injury between the sports differed, with soccer players sustaining the majority of their injuries to the lower limbs, whereas the injuries to rugby players were distributed throughout the body. This makes sense when you consider the physical demands of the sports, and the permitted types of physical contact. Two hundred and sixty one injuries were reported among the soccer players, and 340 among the rugby players. On average, the soccer players played more matches per player than did the rugby players. The rate of injury was higher among rugby matches than soccer matches, but as has been noted in other studies, the great majority of injuries were relatively minor soft tissue injuries. Approximately 20% of all rugby injuries required players to miss matches, compared to 30% of all soccer injuries. The rate of injury among youth soccer players in New Zealand was substantially higher than in similar groups of youth soccer players from European countries. Getting back to the conclusions of the authors – is the rate of injury in youth rugby high? If it is, is it unacceptably high? My philosophy on the matter is that within rugby we should do our utmost to prevent those injuries that result in permanent disablement. We should base our injury prevention initiatives on the best available evidence, and look to eliminate avoidable injuries. I would include among avoidable injuries the following:

- those that occur due to deliberate acts of dangerous play,
- those related to inadequate physical preparation for the demands of the sport
- those related to lack of practice and development of the techniques required in the contact phases of the game
- injuries resulting from unsafe environments (e.g. glass on fields)
- injuries occurring due to inadequate rehabilitation from previous injuries and premature return to the sport

We need to continually monitor the types and frequencies of the injuries that are occurring, and the circumstances associated with them. This will allow us to both measure whether our existing injury prevention initiative's are working as planned, and whether there are new risks emerging as the sport continues to evolve.

The most effective injury prevention initiatives in rugby have been changes to either laws or practices around the contact aspects of the sport. For example, tighter referee control around the sequence of engagement in the scrum has led to a marked drop in spinal injuries in scrums in New Zealand. Education of participants and coaches also plays a part in decreasing the risks. However, I believe we should act cautiously when considering intervening with the laws or structure of the game. There have been examples of law changes instituted for one purpose resulting in unforeseen consequences in later years. The changes to binding in the scrum that led to the development of power scrummaging provide a cautionary example of this.

Risk, in and of itself, is not a bad thing. The ability to face risks and overcome them is an important part of learning how to survive and cope in a world that is inherently risky. Every moment of your life, whether or not you are aware of it, you face some level of risk of death or injury. Sooner or later, the moment when the risk of death reaches 100% arrives for all of us. It is a natural human instinct to try to protect ourselves and those close to us from unnecessary risk. But this needs to be balanced. What is important is to understand risk, and to keep it in context.

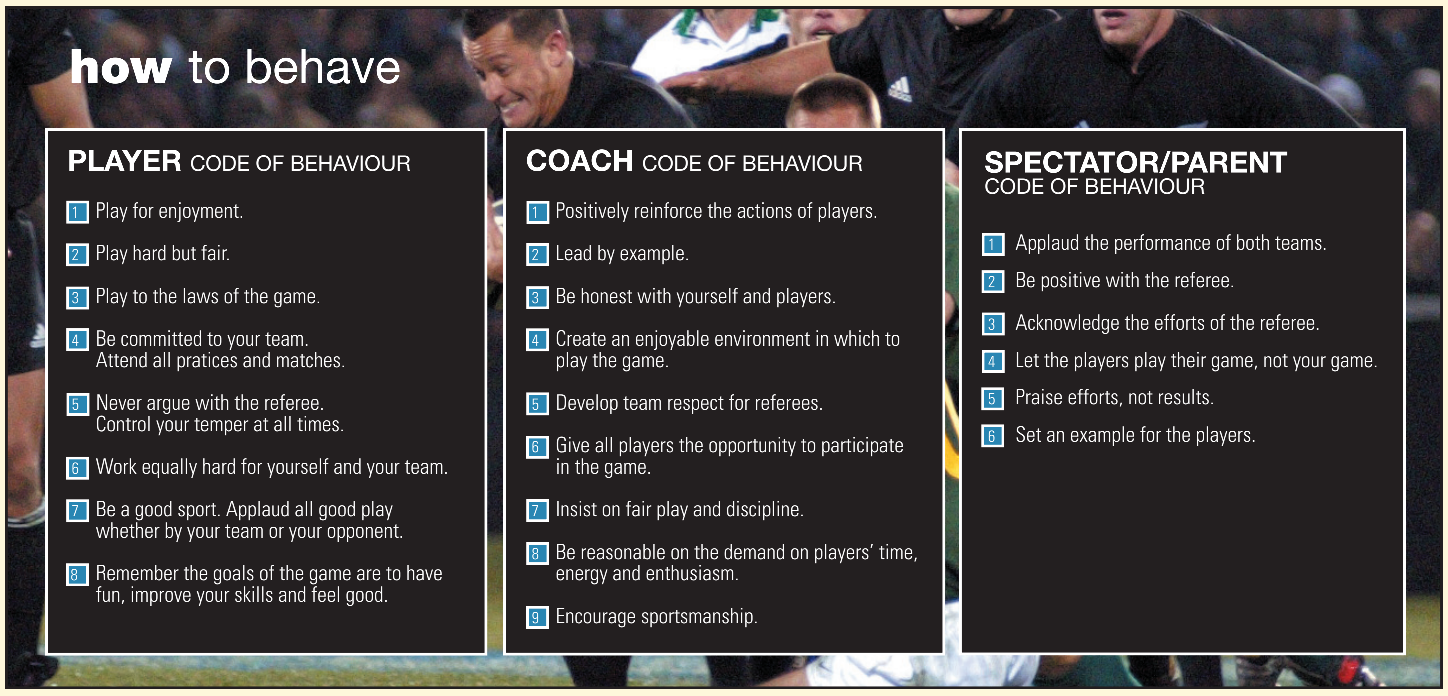
The risks associated with some activities are immediate and tangible – such as the risk of injury due to falls when mountain climbing, or the risk I would face if I attempted to tackle Jerry Collins. Some risks are less obvious, and can result in outcomes that occur well after the exposure – an obvious example is cigarette smoking. Another example, which is becoming increasingly apparent to those interested in public health are the risks associated with a sedentary lifestyle. Sitting on a sofa watching television or playing video games might carry a low risk in the short term, but if it is a habit that forms part of a sedentary lifestyle it is likely to be increasing the risks of early death due to factors such as heart disease, diabetes and stroke. And sometimes, the activities that appear the most routine are actually those that carry the highest level of risk. Every year slips and falls around the home result in broken bones, and occasionally, paralysis. The average person is probably at the highest risk they face in a typical day when they are travelling on the roads – whether by car, motorcycle, bicycle or as a pedestrian. It is my contention that the impression of the level of risk associated with various events and activities is at odds with reality among large sections of the population. If people's fear matched their level of risk, they should probably fear driving to the airport more than the risk of running afoul of a terrorist act on their travels. Perhaps it is to do with the perceived control that people typically feel as they walk, or drive or cycle, as opposed to the lack of control they feel they have over people they don't know who are determined to harm others.

In fact, trying to avoid all risk is likely to be counterproductive – and will merely shift the types of risks that are faced from one sort of injury or illness to another. And a life devoid of risk is likely to also be a life devoid of fun. It appears that some people are naturally predisposed to accept a greater level of risk in their lives than others. Whether a particular activity carries a level of risk that is unacceptable is ultimately a decision that the person (or in the case of young children their parents) has to make. It is my belief that there has been a perception among many parents over the past few years that the level of risk in junior rugby is greater than it actually is – fuelled in part by the 'big hits' they see in televised matches involving professional players, and partly due to the attention given by the media to any serious rugby injuries that do occur. Other activities, especially those that involve people travelling at high speeds (e.g. skiing, motor sports, hang-gliding, parachuting and equestrian), also result in serious injuries, yet seem to result in less media scrutiny than rugby injuries that result in the same outcomes. The amount of attention rugby injuries receive in the media is not necessarily commensurate with either the number of injuries occurring in rugby versus other activities, or the underlying level of risk faced by participants taking part in the activities. In one sense, this is a result of the New Zealand passion with things rugby. It is important that people are aware of this when they consider how risky playing rugby is for themselves or their children. This is not to try to minimise the effect that serious injuries have on the lives of those who do suffer them – but it is important that risks are kept in perspective.

The risk of injury in rugby is primarily associated with the impacts that are part and parcel of the sport. In the Small Blacks to All Blacks model for junior rugby, contact is gradually introduced into the sport, along with coaching of the safest and most effective techniques for players to learn when involved in the contact situations. The idea behind this progression is that the level of risk within the game is better matched to the skills and abilities of the players of particular levels.

There is, however, a small but important proportion of injuries that are immediately preventable. A study of rugby injuries conducted in 1993 indicated that 13% of all injuries were the result of foul play . The nationwide injury surveillance programme conducted by the Injury Prevention Research Unit of the University of Otago in 2003 reported that – guess what? – 13% of all injuries were the result of foul play. A reduction in the rate of injury of 13% would lead to a game that is more popular, and more fun. Injuries to players as a result of deliberate acts of foul play are unacceptable – they are an anathema upon the sport, and run directly counter to both the spirit and the laws of the game. Playing to the best of your ability within the laws and spirit of the game is something to be aspired to. Players who conduct themselves in this way, such as Michael Jones, are universally respected and admired. 'Getting away' with dangerous play to gain a competitive advantage is cheating, and as such deserves to be treated with contempt. In addition, the police have already shown a willingness to launch criminal investigations into deliberate dangerous play that results in injury. As part of the Small Blacks to All Blacks programme, codes of behaviour for players, parents/spectators and coaches have been developed. These outline what is expected of rugby participants, and are shown below.

I am not a parent, but would like to be one at some stage. Based on my knowledge of the levels of risk involved, if my child wished to play rugby at the junior levels, I would strongly encourage them to do so. Small Blacks rugby helps develop a wide range of motor skills – passing, catching, kicking, running, dodging. Learning to fall safely, and developing confidence in physical contact are good things, and transfer to other areas of life. But the main reason I would encourage them to play is because I remember how much fun it was playing when I was a child. On the other hand, if they chose not to play I would not force them into it – but their other option would not be sitting on the sofa playing video games!



how to behave

PLAYER CODE OF BEHAVIOUR

1. Play for enjoyment.
2. Play hard but fair.
3. Play to the laws of the game.
4. Be committed to your team. Attend all pratices and matches.
5. Never argue with the referee. Control your temper at all times.
6. Work equally hard for yourself and your team.
7. Be a good sport. Applaud all good play whether by your team or your opponent.
8. Remember the goals of the game are to have fun, improve your skills and feel good.

COACH CODE OF BEHAVIOUR

1. Positively reinforce the actions of players.
2. Lead by example.
3. Be honest with yourself and players.
4. Create an enjoyable environment in which to play the game.
5. Develop team respect for referees.
6. Give all players the opportunity to participate in the game.
7. Insist on fair play and discipline.
8. Be reasonable on the demand on players' time, energy and enthusiasm.
9. Encourage sportsmanship.

SPECTATOR/PARENT CODE OF BEHAVIOUR

1. Applaud the performance of both teams.
2. Be positive with the referee.
3. Acknowledge the efforts of the referee.
4. Let the players play their game, not your game.
5. Praise efforts, not results.
6. Set an example for the players.

APPENDIX 6

RUGBY INJURIES ARE **NOT** ACCIDENTS

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JUNE, 2005

KENNETH L QUARRIE

Rugby Injuries are NOT Accidents

KEN QUARRIE

People used to believe that injuries in rugby were just part of the game and were the result of 'bad luck'. While injuries have indeed been part of rugby throughout the history of the sport, one of the major changes that has taken place regarding thinking about injuries over the past 30 years is a realisation that the injuries that occur in rugby are predictable, and are a reflection of the activities that take place in the sport. Rugby injuries are not accidents. Accidents are things that happen as a result of unforeseen circumstances. Injuries in rugby follow predictable patterns, and are associated with particular events within the sport. Coaches and referees need to understand this, because players have identified them as being the people they look to for advice on how to help them avoid injuries. Injuries and the fear of injuries are important factors in players leaving the sport, and coaches who can minimise the risk of injuries to their players improve their chances of having more players available for their teams.

What does saying that injuries are predictable mean for rugby? At present, it doesn't mean we have the ability to say "That player will be injured in a game this week because of this, that and the other risk factors that they have." At the level of individuals, there is still a good deal of uncertainty about when and in what circumstances any particular player will be injured. At the level of groups of players, it means that the typical numbers, types and severity of injuries will tend to be reasonably similar (with some variation) from group to group.

Coaches know that if they have their best players fully fit and on the park their team stands a better chance of performing to its potential. One of the aims of *RugbySmart* is to provide information to coaches and referees that they can use to help players avoid injuries. Avoidable injuries include:

- those that occur due to deliberate acts of dangerous play;
- those related to inadequate physical preparation for the demands of the sport;
- those related to lack of practice and development of the techniques required in the contact phases of the game;
- injuries resulting from unsafe environments (e.g. glass on fields);
- injuries occurring due to inadequate rehabilitation from previous injuries and premature return to the sport.

To put in place sensible injury prevention measures for rugby, we need to know about injuries, especially about the following aspects of injury:

- How common are injuries? How many injuries typically occur in rugby given a certain amount of play?
- What are the typical types of injuries?
- What parts of the body are most commonly injured?
- Does the rate of injury vary by level?
- Does the rate of injury vary by position?
- What parts of the game do injuries occur in?
- Are there typical ways (mechanisms) that injuries occur?
- What do coaches, players and referees think about injuries?

To prevent injuries causal factors need to be identified, and their relative importance established. While a number of factors that put players at higher risk of receiving injuries have been identified, there are still a large number that have not been systematically studied. To help identify risk factors, some researchers have grouped them into factors associated with the person playing the sport, and factors associated with the sport itself. Some of the potential risk factors for injury in rugby are shown below.

Obviously the categorisation into one group or the other is a little arbitrary. Depending on how you want to think about things, grade and position could be considered factors associated with the sport, rather than the player.

2004 NATIONAL RUGBY INJURY SURVEILLANCE PROJECT

This project was conducted by Injury Prevention Unit (IPRU) of the University of Otago to provide research about risks and trends in injuries, and safety-related behaviour. It is the continuation of a project that started collecting information on samples of players from various levels in 2002. In 2004, 704 players from throughout New Zealand were followed-up on a weekly basis to find out how much time they spent playing and practicing rugby, whether they received any injuries, and their behaviour regarding injury prevention and injury management. The key findings of the study were:

The coach is the preferred source of information about injury prevention for most players

Almost all players in the study believed that coaches had a role to play in injury prevention, and 70% of players nominated coaches as their preferred source of information about how to avoid injuries. Physiotherapists, television and team managers were also nominated by players as important sources of information.

Foul play accounts for about 12% of injuries

The percentage of injuries related to foul play has remained steady at about 12–14% over the studies of injuries done by the IPRU over the past 13 years. I believe that foul play is cheating, and should not be part of the game of rugby. While a tacit acceptance of certain types of foul play (e.g. punching an opponent in retaliation) may have been prevalent in rugby 30 years ago this type

Extrinsic Risk Factors	Player-Related Risk Factors
Laws of the game	Grade
Illegal play	Age/maturity
Match play	Experience
Phase of play:	Position
tackle	Skill
scrum	Anthropometric characteristics (body size and shape)
ruck/maul	Congenital abnormalities of the spine
Time of season	Physiological characteristics
Environmental conditions:	(e.g. strength/anaerobic fitness)
temperature	Psychological characteristics
climatic conditions	Information processing ability
Pitch hardness/condition	Visual acuity
Referee's control of the game	Impairment by fatigue/alcohol/drugs
Coaches' instructions to players	Occupation
Importance of game:	Gender
trials/finals etc	Ethnic origin

of attitude is less common in today's game. The combination of increased powers of referees and touch judges to deal with foul play through yellow and red cards, improved rugby judicial procedures, scrutiny and disapproval from television and other media, concern from parents over injury risks, and examples of police willingness to prosecute players for assault have all contributed to a change in public perception about what sort of behaviour is acceptable on the sports field. There have been cases in which foul play has been implicated in deaths and permanently disabling injuries in New Zealand rugby – only a few over a long period, but even one is one too many.

Only 8% of injuries caused by punching/striking resulted in penalties in 2004, as against 47% of injuries resulting from high/dangerous tackles. So, why hasn't the rate of injuries from foul play dropped over the past decade? Do referees, coaches and players believe that it is acceptable? Do parents, teachers and administrators think that getting away with cheating in the form of foul play is okay? If so, why? If not, why aren't they doing something more about decreasing it?

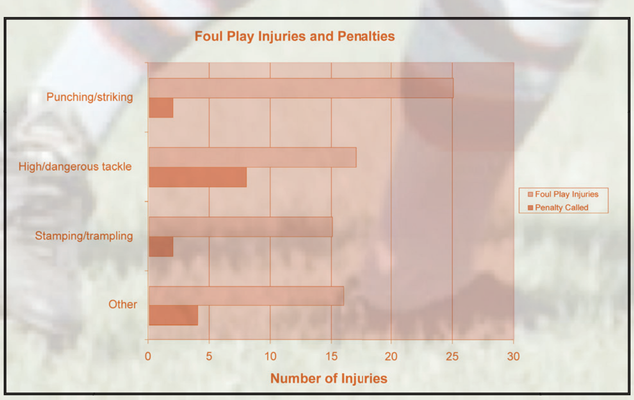
In 2004 a lower proportion (22%) of the injuries that players believed to have been the result of foul play were penalised by the referee than has been the case in previous years (27–31%). If this decrease reflects a less vigilant approach on behalf of touch judges and referees with respect to eradicating foul play than has been the case in the past it is a cause for concern.

Injury is related to level of play

Young players (aged 13–15) receive one injury during a match that requires treatment or stops them from taking part in games or practices for every 16 matches they take part in. At age 16 and above, the frequency was one per eight matches.

This increase in rate by level of play is consistent with other studies. Although there have not been any studies specifically examining why the rate increases, common sense would suggest the following factors may play a role:

- There is an increase in competitiveness as players move up the levels. If players are considered to have a certain amount of capacity for dealing with the loads that are part of the game, then pushing closer to their limits increases the likelihood that they will receive an injury.
- Larger, more powerful players can generate more momentum and hence transfer greater energy to opponents in collisions that take place in tackles, rucks, mauls and scrums.
- At the higher levels of the sport the game is played at a faster pace, and the ball is in play for a greater proportion of the total match, hence there are more contact situations per match than at lower levels.



The rate of injuries for players aged over 16 appears to have increased over the past three years. The extent to which this reflects a real change in injury rate versus a change in depth of data capture is difficult to assess, but is something that we need to keep a close watch over.

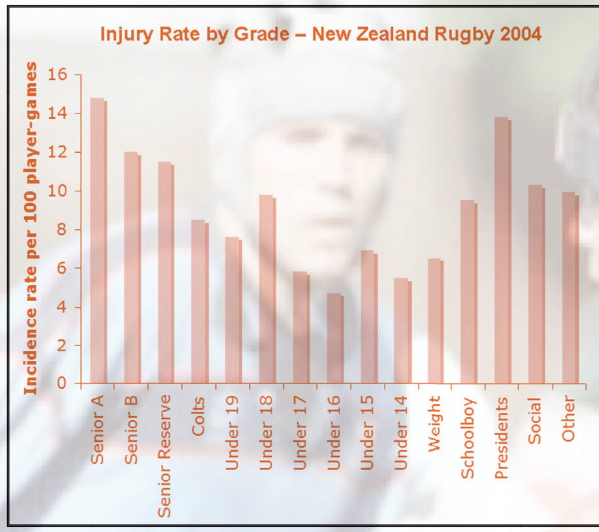
Injury is related to phase of play

This finding is consistent with other studies of rugby injuries. Most rugby injuries occur in the contact phases of the game. Tackles and the breakdown (ruck and maul) carry a high risk of injury because they typically involve high energy collisions between players, and are reasonably dynamic: no two tackles take place in exactly the same way.

Phases of Play	Under 16	16 and Over
Tackle	53 (36%)	155 (33%)
Ruck	26 (17%)	83 (18%)
Open play	18 (12%)	84 (18%)
Maul	16 (11%)	39 (8%)
Scrum	10 (7%)	37 (8%)
Line out	2 (1%)	8 (2%)
Other	24 (16%)	63 (13%)

Observers of rugby will have noted the large increase in the number of tackles and rucks that has occurred since the mid-1990s. Peter Thorburn has suggested that this was a result of the 'use it or lose it' law around the maul, which meant that a tackler was less likely to attempt to remain on their feet following a tackle because of the risk of losing the ball if a maul formed and the ball carrier's team did not make forward progress. It is not only the number, but the typical character of tackles and rucks that has changed over time. What is not known for certain is whether tackles and rucks have become riskier on a per event basis as opposed to them just becoming more frequent (i.e. there are more of them than their used to be, so if the risk per event stayed the same you would expect to see more injuries).

Even with the changes to the nature of tackles and rucks, there



are some key factors that decrease player risk and conversely some actions that can greatly increase the risk of players receiving an injury. Deliberate high tackles and stiff arm tackles can create large forces around the head and neck area, and carry a risk of serious injury to the ball carrier. Since I have been working at the NZRU, I know of one death through a player being struck a blow directly on the throat during a high tackle and several others that have occurred during tackles. There have been one or two deaths per year as a result of rugby in New Zealand over the past five years. One of the most dangerous positions a player can assume is to drop their chin towards their chest as they enter contact in tackles, rucks, mauls and scrums. Instructing players to 'put your head down and go for it' is bad advice, but we still see players – even some players at professional level – doing exactly that. Placing the head in this position in the 'squeeze ball' maneuver also places the player at risk. Coaches need to instruct players not to get into a position where a blow to the top of the head can occur to a player who already has their head tilted forward.

Injury is related to position

Loose forwards were found to have the highest rate of injury, and outside backs the lowest. The looseforwards are typically the players who are most heavily involved in tackles and breakdowns in each match. These are the phases of play in which the greatest numbers of injuries occur. This is probably no surprise to you if you are a coach, but it has implications in terms of squad selection and numbers of players that you need to have available to cover for injuries that do occur. The laws of rugby mandate how many front-row reserves teams must have available, but the make-up of the remaining positions is up to the coach. Smart coaches will select players who can not only fill several positions, but will also take into account the relative risk of their players within specific positions being injured.

Positional Groups (per 100 player-games)	Under 16	16 & Over
Front row	6.2	10.7
Locks	5.4	12.2
Loose forwards	8.7	13.8
Inside backs	5.0	13.0
Centre backs	7.2	12.4
Outside backs	5.7	11.3

Injuries are distributed over the body

While rugby injuries are distributed throughout the body, the proportion of injuries to various body parts also varies by position. For every 100 injuries a forward received, 36 were to the head and neck, against 23 for the backs. A greater percentage of injuries sustained by backs were to the lower limb (40%) than was the case for the forwards (31%).

Body Region	Forwards	Backs
Head and neck	118 (36%)	66 (23%)
Upper limbs	63 (19%)	62 (22%)
Torso	45 (14%)	37 (13%)
Lower limbs	102 (31%)	112 (40%)

Aside from the head, the knee, shoulder and ankle are the most commonly injured body parts. Concussion accounted for 8% of injuries to both forwards and backs, with fractures and dislocations making up another 9% of injuries for forwards and 10% for backs. By far the most frequent injuries in rugby are sprains, strains and haematomas, which collectively accounted for 62% of injuries for forwards and 67% for backs. This pattern has been seen in most studies of rugby injury. These injuries should be treated following the guidelines outlined in the *RugbySmart* materials.

Injury is related to time in the season

For players aged under 16, the rate of injury peaked in the middle of the season. For players aged 16 and over, the rate of injuries was highest early in the season, dropped through the middle of the season, and increased slightly towards the end of the season. This pattern has been seen in other studies, and has been noted in the frequency of spinal injuries per month.

A number of reasons for this pattern were suggested when *RugbySmart* was first developed in 2001. These included:

- Lack of experience
    - Players are probably more likely to take up a new position at the start of the season.
    - New players generally enter the sport at the start of the season.
    - Combined lack of familiarity in the front row: players who are not used to each other may be unsure of their combined course of action in the event of a collapsed scrum.
- Lack of continued practice at the skills involved in the contact phases of the game.
    - Players do not usually practice tackling, scrummaging, rucking or mauling in the weeks leading up to the season. This may lead to them being more likely to be placed in physical positions that can result in injury.
- Lack of appropriate conditioning
    - Players often perform aerobic, anaerobic, speed, strength and power training over the off season. Conditioning the body to cope with the impacts that are a major part of rugby were ignored by the majority of players (although this is beginning to change). Players, even those who have trained to increase their aerobic fitness and strength are generally at their 'softest' at the beginning of the season.
    - The first matches of the season are often trials, where players are likely to play as hard as possible in the attempt to make the team they aspire to. In most cases, there is little 'progressive overload' in terms of impact.
    - There are often fewer front-row players available than looseforwards, so those front-row players who are available end up spending larger amounts of time on the field during trials than do players in other positions.
- Environmental Conditions
    - Harder grounds at the beginning of the season, which leads to increased impact forces when players hit the ground after tackles and during rucks, mauls and collapsed scrums.

There may well be others, and if you think of any let me know, because we can build in further recommendations to *RugbySmart* as we go on.

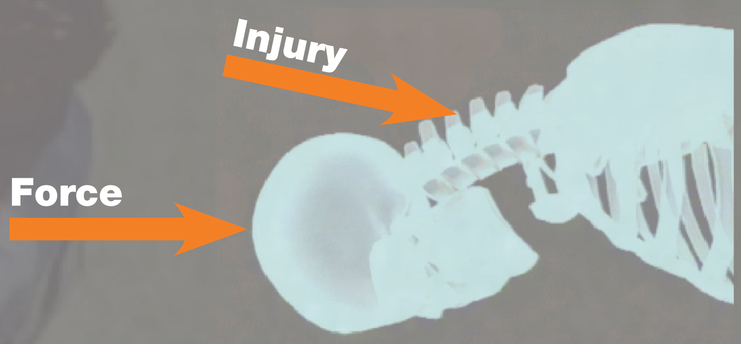
Injury is related to injury

The definition of injury in the National Rugby Injury Surveillance Project was "an injury that caused a player to miss at least one scheduled game or practice, or seek medical treatment." In 61% of injury events, the player continued to play after the injury. With the benefit of hindsight, the player believed that they should not have returned to play in 27% of those cases (i.e. 16% of all injuries). Other studies of injuries have indicated that injury predicts further injury. This is likely to be associated with players returning to games and practices prior to complete healing and rehabilitation. Coaches who understand this typically try to mitigate the risk by improving the skills of all the players in their squad and placing less pressure on players to resume play until they are completely over their injury.

Summary

Rugby is a physical contact sport, and all players face some risk of injury every time they take the field. This risk is due to the nature of the activities that comprise the sport. Injuries in rugby are not random 'accidents' but are a reflection of the activities that comprise the sport. Identification of risk factors, education of participants about what the risk factors are, and adherence to the laws of rugby can help coaches, referees and players reduce the risk of avoidable injuries.

Hyperflexion of the neck is the most common mechanism for spinal injuries in rugby



APPENDIX 7

PLAYER MANAGEMENT FOR TEAM SUCCESS

PUBLISHED IN GAMEPLAN RUGBY, THE NZRU COACHING JOURNAL

OCTOBER, 2005

KENNETH L QUARRIE

WILL G HOPKINS

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Player Management for Team Success

Ken Quarrie, NZRU and
Will Hopkins, Sport and Recreation, AUT

We believe that as a result of the changes to rugby over the past decade, coaches need to re-evaluate the way they manage players through a competitive season. The following points are our opinions, but are based on a combination of the personal playing experience of one of us (a long time ago!), training teams and players (some time back) and scientific examinations of match patterns (recently).

Key Points:

- The contact load faced by players in competitive rugby has increased greatly over the past decade – there are more rucks and tackles, and player size (at many levels of the sport) has increased
- There appears to have been an increase in injury rate at the higher levels of the sport over the past decade
- Players who are injured typically can't play to their usual standard, and are more prone to further injuries until their injury is fully healed. Taking a progressive approach to bringing a player back to play can help reduce the chances of them being re-injured and being unavailable for longer periods
- Managing total training and match load of players across a squad increases your chances of being successful in a competition – communication with players (and other coaches if the player is in more than one squad) about how much training and physical work they are doing outside of the work they do in sessions with you is important.
- Identifying player strengths and weaknesses early in the season and devoting time to improving the individual skills of players can help increase squad 'depth'. In modern competitions the team or club with the best 'first 22 (or first 30!)' often wins out in a competition over the team with the best 'first XV'.
- Improving the skills of all players within your squad through dedicated individual and small group skills training over a season or several seasons is a worthy coaching goal and will improve your chances of success
- Not all matches within a typical competition structure are equally important if your goal at the beginning of the season is to make the play-offs. Picking your battles may help you win the war
- Providing less experienced players with match time in less important matches can help them become accustomed to the demands of the level of play before they are called on to perform in 'must-win' matches.

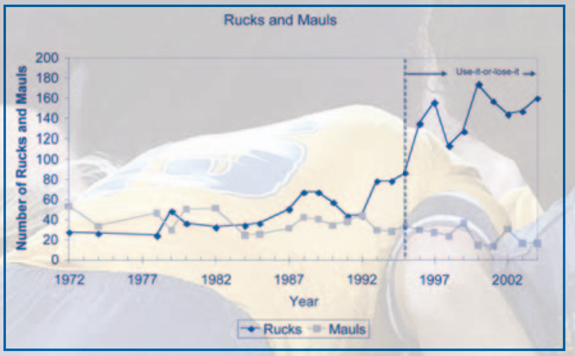
Changes in rugby over the past decade

To say that rugby has changed since the introduction of professionalism will be possibly the most obvious statement ever published in this magazine. In fact, rugby has a long history of changes to both the laws (and the interpretation of the laws preferred at a given point) and the patterns of activity on the field. Some people have thought of rugby as a 'survival of the fittest' where any change to the laws results in coaches and players adapting to the law change and trying to maximize their competitive advantage. Some of the major law changes through the last decade or so have been the introduction of the 'use-it-or-lose-it' law, changes to allow lifting in the lineout, changes to the referee's control at scrum-time, the introduction of non-injury substitutes and the carding system for temporary and permanent removal of players. Let's have a look at a couple of these, and the implications that arise from them in terms of managing the workload of players to maximize team success through a competition.

The use-it-or-lose-it law and non-injury substitutions

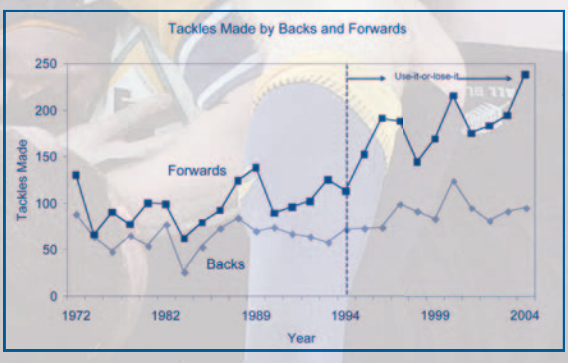
- The contact load faced by players in competitive rugby has increased greatly over the past decade – there are more rucks and tackles, and player size (at many levels of the sport) has increased.

Peter Thorburn has pointed out that because of the introduction of the use-it-or-lose-it law in 1994, creating a ruck following a tackle became a safer option in terms of ball retention for the team in possession than creating a maul. The following two graphs show how the number of rucks, mauls and tackles has changed over time. NZRU information from the first Bledisloe Cup match in each year is shown.



Following the introduction of the use-it-or-lose-it law both forwards and backs faced higher levels of contact during matches than had been the case in the past. From the graph above you can see that the increase in the number of rucks and repeated 'runners' close to the ruck has greatly increased the demands on forwards to make tackles. The ability to demonstrate repeated power and endurance through high-intensity, intermittent activity became more important aspects of fitness.

Another significant law change occurred in 1997. This was the introduction of non-injury substitutes. The effect of this law change was to decrease the average time spent on the field per player. While 'being subbed' is now much more accepted by players as part of the game, when this law change was first introduced there was a good degree of



resistance among players to the concept of being taken from a match if they weren't injured. Over time, however, as it became apparent to top coaches how great the load that multiple high levels matches every year placed on players, coaches started looking at ways to manage the amount of exposure to rugby that their top players faced.

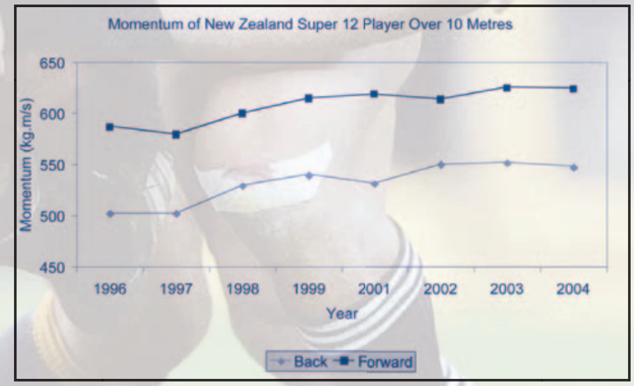
Player size and momentum in contact situations

We believe that the combination of greater contact load along with the ability to substitute players facilitated the rapid increase in body mass of players that occurred around the time of the switch to professionalism in 1996. As shown in earlier articles in gamePlanRugby, the average mass of All Blacks forwards increased from around 102 kg per player in 1995, to 111 kg per player in 2004. The average mass of the backs increased from 83 kg to 96 kg. The physiques of backs have become similar to that of a typical loose-forward from 10 or 15 years ago.

Backs are much more involved in contesting the ball in the post-tackle situation than used to be the case. This has meant that being more physically robust is a greater advantage for backs than used to be the case. If players are able to maintain speed, having greater mass allows them to generate more momentum, which is an advantage in contact situations. The extra conditioning undertaken by players has also led to improvements in sprinting speed, which again helps players to generate momentum.

Injury rates

- There appears to have been an increase in injury rate at the higher levels of rugby over the past decade



Note: No information was available from the 2000 season.

Evidence from Australia and the UK suggests that the rate of injuries in rugby increased following professionalism. It may be that the extra conditioning undertaken by players does not overcome the risk presented by the increased frequency of high energy collisions if everyone else also gets bigger and more powerful. A recent study of professional players in the UK reported that around 23% of players were unavailable for matches at any given time due to injury.

Implications of these changes to squad management

"In theory, there is no difference between theory and practice. But, in practice, there is." ~ ***Jan L. A. van de Snepscheut***

Now, we realize that in many areas just getting 15 players available for your team is tough, so, some of what we are going to say may be less applicable to you if you are in that situation. But smart coaches have the ability to take an idea, evaluate it, use what applies to them and discard the rest.

Squad size and communication across teams

The evidence from a number of studies suggests that the injury rate increases as you go up the grades. But let's imagine that the rate of injured players is similar to that above for the team that you coach, and around 20% of players are unavailable because of injury at any one time. If you have a squad of 22 players this means that you would expect to have around 17 or 18 players fit and available. At senior club level this means that you will need to be looking beyond your squad of 22 players a reasonable amount of the time if you want to have seven fit reserves available. Do the players that you will look to bring in know your systems and calls? How many times has a critical lineout been lost because a new hooker or lock hasn't known the team lineout calls?

- Managing total training and match load of players across a squad increases your chances of being successful in a competition – communication with players (and other coaches if the player is in more than one squad) about how much training and physical work they are doing outside of the work they do in sessions with you is important.

For three, or maybe even four weeks within a typical club competition structure, it probably doesn't matter hugely whether you manage player workload to any extent. Most players will be able to handle the demands of playing three or four consecutive matches that are a week or so apart. Whether they can continue to perform near their personal 'peak' level if you continue to play them week-in week-out for eight to 10 weeks is another question altogether. We don't believe many coaches have grasped the concept of 'squad management' as effectively as they could have to improve their chances of success in any given competition. For example, we know of front row players who have played on a Saturday for their club side, done 50 plus scrums on a scrum machine at a Monday training for a rep side, done scrum training again on a Tuesday for their club side, and played a pre-season rep-match on a Wednesday evening. This is counterproductive. The player does not have enough recovery time to allow for any improvement in strength or skill to take place. Improvement in skills and fitness does

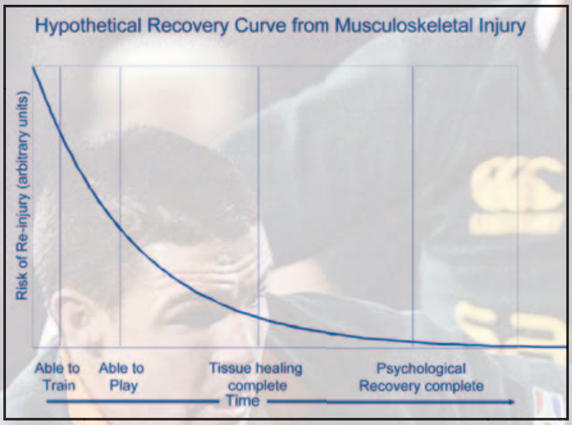
not happen until after recovery has taken place. Communicating across teams and working towards the long term improvement of the player will pay off for all the coaches and teams with which a particular player is involved.

What about managing the exposure to matches of your 'best' players? It is well known that people have differing abilities to recover from physical activity. While playing the 'first XV' within a squad for every game in a competition might have been the best approach to take in years gone by, it may no longer provide you with the best chance of doing as well as you can in the competition. This is because the ongoing 'niggles' – the bumps and bruises that all players receive through a season - can add up. Imagine an injury being the result of a transfer of energy to the body that exceeds the ability of the tissues to maintain their structure and/or function. Tissues have a certain amount of capacity to absorb energy. If the structure of the tissues have previously been compromised by lots of smaller 'sub-injury threshold' impacts, without having the ability to recover completely from them, the risk of any further contact resulting in injury increases.

What we don't believe has been well understood by many people is just how much recovery time is required from the physical contacts in modern rugby. These vary from position to position and to a certain extent from game to game. Generally, though forwards face a higher per match contact load than backs, and within the forwards the front row players and openside flanker face a higher contact load than the remaining forwards. Depending on the amount of contact, it can take anywhere from 48-96 hours for a player to recover from the physical contacts received in a match and be ready to play again at the same level as the previous match. Through the season, the game can be considered the peak 'conditioning' session of the week for those players who take the field.

Risk of re-injury

- Players who are injured typically can't play to their usual standard, and are more prone to further injuries until their injury is fully healed. Taking a progressive approach to bringing a player back to play can help reduce the chances of them being re-injured and being unavailable for longer periods



Presumably, the risk of re-injury following an initial injury decreases over time as the healing process proceeds (the above curve is hypothetical). From our experience with teams, it often seems that as soon as a player is able to take the field people assume 'the player has recovered from injury' and are then ready to take a full part in all future team and individual training sessions. We don't believe this is the case. If a player had recovered fully from injury, you would expect them to be at no higher risk than they were when they were first injured. But studies around the world in sports injuries, both for rugby and other sports, show that players who have been injured are at higher risk of re-injury. We think managing the playing and training load over a longer period than until the player first takes the field again will help reduce the risk of re-injury. We would advise coaches to communicate closely with the player and any medical/fitness practitioners the players is working with and let them know that their long-term position in the team does not depend on them being on the field half-fit – not because we wouldn't want the player back as soon as possible, but because we don't want them back for half a game and then unavailable for the next three or four matches through re-injury.

Calculating the odds for team success

- Not all matches within a typical competition structure are equally important if your goal at the beginning of the season is to make the play-offs. Picking your battles may help you win the war.

We would all like to believe that our team will race through the competition like a juggernaut, destroying every team we meet and winning the championship at a canter. Unfortunately, that is not going to happen very often, if ever for most coaches in their coaching careers. Even successful teams seldom get through an entire season unbeaten (we know, there are always exceptions, like the team somewhere that hasn't lost for years!) So, let's imagine that you are a coach of a competent team, and that the team goal is to make the top-four to provide themselves with a shot at winning the competition. Is every match of equal importance as you go through the competition? No – for a couple of reasons. First, in any competition there will be stronger and weaker teams. Second, the points structure in most competitions means that you can lose a certain number of matches and still make the play-offs. So, sometimes you may have to pick your battles carefully if you want to win the war. This has implications regarding when through a competition you should be looking to bring your squad to peak fitness. If it is too late you may already be out of the running by the time the team is really hitting their peak. If it is too early you may find that they are unable to maintain their level when the matches that decide the competition roll around.

Progressive loading followed by sufficient time for recovery is one of the key concepts for improving physical condition – especially early in the season, when the injury rate tends to be at its highest. Typically, we would advise players to enter the season with a good strength and aerobic fitness, build progressively into contact through the pre-season, and look to improve anaerobic endurance throughout the season while maintaining as much strength as possible. Although there are many recovery strategies used at various levels of rugby, one of the best and simplest is for players to get a good night's sleep following a match, and to avoid excessive alcohol.

When one of us was working as a trainer (KQ) he would discuss with the coach which of the upcoming games were considered the 'toughest'. Generally, the coach and trainer would work the players harder on a training early in the week (usually Tuesday) before an 'easier' match (backing the ability of the team prevail even if they were a little flat), and then back off the volume of training the following Tuesday before the harder match to let the players recover to be in as good condition as possible for the tough match. Working harder (or, especially, working longer) in the week of harder matches may not always be the best approach.

Individual and mini-unit skill development

- Identifying player strengths and weaknesses early in the season and devoting time to improving the individual skills of players can help increase squad 'depth'. Improving the skills of all players within your squad through dedicated individual and small group skills training over a season or several seasons is a worthy coaching goal and will improve your chances of success

We have probably all seen players making mistakes early in the season, and groaned when they make exactly the same mistakes later in the season. Even in high level teams players who have poor handling skills or tackling skills are quite common. Just telling a player that they need to improve, however, is not enough. As a coach, you need to help them improve. If the player is making the same sort of errors at the end of the season as they were at the beginning, what does this tell you about yourself as a coach? Work with players who have difficulties with specific skills. If you are unsure about how to help players develop individual skills contact your local provincial union and ask for help. Get hold of resources – check out the NZRUGBYNET web-site. Setting specific skills goals early in the season and helping players work towards them in a progressive manner is a good way to begin.

Progressively building player experience through a squad

Experience is a key aspect of team success. You only have to look at a good team (for example Australia in 2005) that has a number of injuries to experienced players in a short space of time to see what a difference bringing untried players into a team makes. Smart coaches bring players in and get them experience in a number of progressively important matches before the 'crunch' matches towards the middle or end of the season (depending on where they stand in the competition at the time) so that the player can cope with the pace and demands of the game when the pressure comes on.

It is worthwhile thinking about when you bring substitute players on in a match. Should you start with the less experienced player in some matches, knowing that if things don't go so well you have your more experience option still available? In such cases you would probably want another reserve who can cover the position in a crisis in case your first player receives an injury early in the match. What about so-called 'impact' players? Should you start a match with them for the first 30 or 40 minutes, rather than bringing them on towards the end of the match? We don't claim to know, but these things are worth thinking about. Innovation is not about doing what everybody else is already doing! Try things out and see what works best for you and your team.

**Just our two cents worth – these are opinions. We want you to think about them and challenge them. What applies to you? Are there ideas here you can use, or are they irrelevant? We are interested in your thoughts – email feedback to ken.quarrie@nzrugby.co.nz*

All the best as you think about planning and preparing for next season!

The winner of the RugbySmart Challenge prize was Paul Hughes from Kaiapoi, north of Christchurch .

Paul was unable to attend the Bledisloe Cup match in Auckland, and we have allowed him to transfer the prize to attending the All Blacks vs. South Africa match in Dunedin.

Ken Quarrie

APPENDIX 8

CONSENSUS STATEMENT ON INJURY DEFINITIONS AND DATA COLLECTION PROCEDURES FOR STUDIES OF INJURIES IN RUGBY UNION

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SHORT REPORT

Consensus statement on injury definitions and data collection procedures for studies of injuries in rugby union

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Br J Sports Med 2007;**41**:328–331. doi: 10.1136/bjsm.2006.033282

Wide variations in the definitions and methodologies used for studies of injuries in rugby union have created inconsistencies in reported data and made interstudy comparisons of results difficult. The International Rugby Board established a Rugby Injury Consensus Group (RICG) to reach an agreement on the appropriate definitions and methodologies to standardise the recording of injuries and reporting of studies in rugby union. The RICG reviewed the consensus definitions and methodologies previously published for football (soccer) at a meeting in Dublin in order to assess their suitability for and application to rugby union. Following this meeting, iterative draft statements were prepared and circulated to members of the RICG for comment; a follow-up meeting was arranged in Dublin, at which time all definitions and procedures were finalised. At this stage, all authors confirmed their agreement with the consensus statement. The agreed document was presented to and approved by the International Rugby Board Council. Agreement was reached on definitions for injury, recurrent injury, non-fatal catastrophic injury, and training and match exposures, together with criteria for classifying injuries in terms of severity, location, type, diagnosis and causation. The definitions and methodology presented in this consensus statement for rugby union are similar to those proposed for football. Adoption of the proposals presented in this consensus statement should ensure that more consistent and comparable results will be obtained from studies of injuries within rugby union.

Wide variations in the definitions and methodologies used for investigations of injuries in rugby union have created inconsistencies in reported data, which has in turn limited the value of individual studies and severely restricted opportunities for making interstudy comparisons of results. Recent consensus statements on injury definitions and procedures for cricket[1] and football[2] have demonstrated an international recognition of the benefits that are gained from the use of common definitions and methodologies. The aim of this consensus statement is to establish operational definitions and methodologies for studies of injuries in rugby union.

METHOD

A preliminary review of the consensus statement produced for cricket[1] identified that these proposals were cricket-specific and would not translate readily to rugby union. The consensus statement from football,[2] on the other hand, showed similarities to definitions and methodologies previously used in peer-reviewed publications of studies of rugby union injuries. The International Rugby Board (IRB) Medical Advisory Committee, therefore, established a Rugby Injury Consensus Group (RICG) in order to make a detailed assessment of the methodology proposed for football and to determine whether these proposals could be adopted in rugby union, and, if this was not possible, to develop proposals that were appropriate for rugby union.

The RICG comprised seven voting members—namely, the Chief Medical Officer of the IRB, who acted as group chairman, and representatives of six national rugby unions (three from the northern and three from the southern hemisphere). Six non-voting members with experience in the study of injuries in a range of team sports were co-opted on to the group to provide a wider perspective and a greater understanding of the issues involved. Before the initial meeting in Dublin, each member of the RICG was provided with a copy of the football consensus statement[2] to ensure that they were familiar with the issues to be discussed. The recommendations proposed by Fink *et al*[3] for consensus group working were adopted during a 12 h meeting. Each definition and methodological issue presented in the football consensus statement was introduced and discussed by the group. Depending on the outcome from these discussions, it was proposed that either the recommendation from the football consensus group should be accepted or alternative options should be presented for consideration. After this meeting, iterative draft consensus statements were prepared and each circulated to members of the group for comment. A follow-up meeting was held in Dublin to finalise the definitions and procedures presented in this statement. At this stage, all authors confirmed their agreement with the definitions and procedures presented in this consensus statement. The agreed document was finally presented to and approved by the International Rugby Board Council.

DISCUSSION

The RICG endorsed the overall philosophy and broadly agreed the detail of the consensus statement presented for football,[2] but, owing to the inherent differences between the games of rugby union and football, it was considered that some changes were required. For clarity, definitions are presented here in the context of rugby union; however, it was not considered necessary to re-present comments on issues where there was agreement with the football statement. Therefore, unless specifically stated to the contrary, it should be assumed that the methods and explanatory notes contained in the football consensus statement form an integral part of this consensus statement for rugby union. The following discussion focuses on those issues where the consensus statement for rugby union departs from the statement presented for football. For comparability and ease of cross-referencing between the two documents, the issues are presented and discussed in the same order as that used in the football consensus statement.[2]

Joint publication: This report is also published in *Clinical Journal of Sport Medicine* 2007, volume 17, issue 3.

DEFINITIONS

Definitions of injury can be broadly categorised into theoretical and operational definitions[4]: in studies of sports injuries, definitions are normally intended to provide pragmatic or operational criteria for recording cases rather than to provide a theoretical definition of injury. Although there is no generally accepted theoretical definition of an injury because of its dependence on context,[4] definitions are broadly based around the concept of ''bodily damage caused by a transfer or absence of energy''. This general concept may be helpful in clarifying whether an incident in rugby should be recorded as an injury.

Injury

The following definition of ''injury'' was accepted:

> Any physical complaint, which was caused by a transfer of energy that exceeded the body's ability to maintain its structural and/or functional integrity, that was sustained by a player during a rugby match or rugby training, irrespective of the need for medical attention or time-loss from rugby activities. An injury that results in a player receiving medical attention is referred to as a 'medical-attention' injury and an injury that results in a player being unable to take a full part in future rugby training or match play as a 'time-loss' injury.

In rugby union, non-fatal catastrophic injuries are of particular interest and therefore a third subgroup of reportable injuries was added:

> A brain or spinal cord injury that results in permanent (>12 months) severe functional disability is referred to as a 'non-fatal catastrophic injury'.

Severe functional disability is defined by the World Health Organization[5] as a loss of >50% of the capability of the structure.

Recurrent injury

The following definition of recurrent injury was accepted:

> An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury. A recurrent injury occurring within 2 months of a player's return to full participation is referred to as an 'early recurrence'; one occurring 2 to 12 months after a player's return to full participation as a 'late recurrence'; and one occurring more than 12 months after a player's return to full participation as a 'delayed recurrence'.

In rugby union studies, however, a sutured laceration that is reopened during a match or training session should be considered to be a recurrence.

Injury severity

Time (days) lost from competition and practice was accepted as the basis for defining injury severity:

> The number of days that have elapsed from the date of injury to the date of the player's return to full participation in team training and availability for match selection

Injuries should be grouped, therefore, as slight (0–1 days), minimal (2–3 days), mild (4–7 days), moderate (8–28 days), severe (>28 days), ''career-ending'' and ''non-fatal catastrophic injuries''.

Match exposure

The following definition of match exposure was accepted:

> Play between teams from different clubs.

However, in rugby union, it is a common practice for clubs and countries to use competitive matches between A and B teams as trials for selection purposes. In these cases, A and B trial teams should be treated as though they were separate clubs and, in the case of fully-refereed competitive trial matches between these teams, the exposure should be recorded as match exposure.

Training exposure

The following definition of training exposure was accepted:

> Team-based and individual physical activities under the control or guidance of the team's coaching or fitness staff that are aimed at maintaining or improving players' rugby skills or physical condition.

METHODOLOGICAL ISSUES

The proposal that injury surveillance studies should, wherever possible, be prospective cohort studies was endorsed. In practical terms, most injury surveillance studies in rugby union will record time-loss and non-fatal catastrophic injuries. Because of the physical nature of rugby union and the high number of slight contusions routinely encountered in the game, studies in rugby union will normally record injuries as time-loss injuries only if they result in more than one day of absence from training and/or matches. The nature of the game of rugby union means that recording injuries will often be more complex than is the case for football—for example, multiple injury diagnoses from a single event and multiple events (with or without multiple diagnoses) involving the same player in the same game are more common in rugby union.

Interpretation of injury definition

Studies should not incorporate mixed definitions of injury; it is anticipated that most studies on rugby union will record time-loss injuries. A blood injury that requires a player to leave the field of play for treatment under Law 3.11(a) should not be included as an injury in a study unless the player subsequently loses time from training or competition as a result of the injury. If, however, the purpose of a study is to record the incidence of blood injuries, then these injuries should be recorded and reported separately from time-loss injuries. Table 1 presents examples of how specific incidents should be recorded using the medical attention and time-loss (>1-day severity) regimens.

Non-fatal catastrophic injuries (permanent severe functional disability) should not include injuries resulting in transient neurological deficits such as burners/stingers, paraesthesias, transient quadriplegia and cases of concussion where there is full recovery.

Injury classification

The requirement that injuries should be classified by location, type, body-side and injury event was endorsed.

Location of injury

The main groupings and categories proposed were accepted, with the additional requirement that the category of thigh

Table 1 Examples of how to record injuries under a ''time-loss'' recording regimen

Example	Injury recording regimen	
	Time-loss (>1 day)	**Medical attention**
1. A hooker sustained an abrasion on the thigh during a ruck. The team doctor cleaned and dressed the injury after the match. The player missed one day of training	This episode should not be recorded as an injury	This episode should be recorded as an injury, severity: 1 day (slight)
2. A flanker sustained a lumbar disc injury during weight training and required 25 days rehabilitation before he could return to full training and competition	This episode should be recorded as an injury, severity: 25 days (moderate)	This episode should be recorded as an injury, severity: 25 days (moderate)
3. A winger sustained a hamstring injury during a training session and required 18 days of rehabilitation before he could return to full training and competition. The player sustained a further hamstring injury to the same muscle in the same leg 3 weeks later during a match. The second injury required 40 days of treatment and rehabilitation	The first episode should be recorded as an injury, severity: 18 days (moderate); the second episode as a recurrence (early), severity: 40 days (severe)	The first episode should be recorded as an injury, severity: 18 days (moderate); the second episode as a recurrence (early), severity: 40 days (severe)
4. A loose-head prop forward sustained a laceration to his head during a match; the player left the field of play to enable the team doctor to suture and protect the injury. The player returned to the field of play. The player continued to train and play with his head bandaged for the next 3 weeks.	This episode should not be recorded as an injury	This episode should be recorded as an injury, severity: 0 days (slight)
5. A fly-half tackled an opposing flank-forward during a match and sustained a dislocated shoulder. The player was unable to play again that season and failed to return to full training the following season. The player retired from playing rugby union before returning to full fitness	This episode should be recorded, severity: career-ending	This episode should be recorded, severity: career-ending
6. A centre suffered a minor ankle ligament injury in a match and was substituted. The player rested the next day under instruction from the team physician and returned to full training on the following day. The player subsequently sustained an injury to the same ankle ligament 7 days later during the next match. She required 35 days of treatment and rehabilitation before returning to full training	The first episode should not be recorded as an injury; the second episode should be recorded as an injury, severity: 35 days (severe)	The first episode should be recorded as an injury, severity: 1 day (slight); the second episode should be recorded as a recurrence (early), severity: 35 days (severe)
7. A scrum half sustained a thigh haematoma on Saturday during a match; as a result of the injury, the player would not have been able to take part in training. However, the next training session did not take place until the following Thursday, by which time the player had recovered and was able to take a full part in training activities.	The episode should be recorded as an injury, severity: 4 days (mild)	The episode should be recorded as an injury, severity: 4 days (mild)

injury should be subdivided into anterior thigh and posterior thigh injuries.

Type of injury

The categories proposed for reporting the type of injury sustained were broadly accepted. However, the headings used for the main groupings were subject to slight change and additional categories within these groupings were added to reflect the injury profile in rugby union—namely, injuries to the head, spinal cord and internal organs. Table 2 shows the full list of main groupings and categories that should be used in rugby union.

Table 2 Main groupings and categories for classifying the type of injury

Main grouping	Category
Bone	Fracture Other bone injuries
Joint (non-bone) and ligament	Dislocation/subluxation Sprain/ligament injury Lesion of meniscus, cartilage or disc
Muscle and tendon	Muscle rupture/tear/strain/cramps Tendon injury/rupture/tendinopathy/bursitis Haematoma/contusion/bruise
Skin	Abrasion Laceration
Brain/spinal cord/ peripheral nervous system	Concussion (with or without loss of consciousness) Structural brain injury Spinal cord compression/transection Nerve injury
Other	Dental injuries Visceral injuries Other injuries

Other injury classification issues

Injuries should be classified as to whether they occurred during a match or training session, and whether they were the result of contact with another player or object or were a non-contact injury. For injuries resulting from contact, activities should be recorded as tackling, tackled, maul, ruck, lineout, scrum, collision or other. It may also be appropriate to record whether the action causing the injury was deemed by the match referee to be a violation of the laws of the game or was deemed by the match referee or citing official to be ''dangerous play'' (Law 10.4).

Study population

The RICG endorsed the view that injury surveillance studies should normally include players from more than one team and should extend for a minimum period of one season, 1 year, or for the duration of a major tournament.

IMPLEMENTATION ISSUES

The format and content of studies should be approved by an appropriate institutional ethics committee and informed consent should be obtained from all players for their data to be included in the study. The formats of the proforma provided in the football consensus statement[2] were accepted as appropriate for use in rugby union. The player's dominant arm should also be identified on the player's baseline information form, because of the importance and higher incidence of upper limb injuries in rugby union. Figure 1 provides an example of an injury form for use in rugby union.

Injury Report Form for Rugby Union

(Team) Player-code: .... Date:...................

1A. Date of injury: ....1B. Time of injury (during match): ....

2. Date of return to full participation: ....

3. Playing position at the time of injury: .... ❑ Not applicable

4. Injured body part:

❑ head/face	❑ upper arm	❑ anterior thigh
❑ neck/cervical spine	❑ elbow	❑ posterior thigh
❑ sternum/ribs/ upper back	❑ forearm	❑ knee
❑ abdomen	❑ wrist	❑ lower leg/ Achilles tendon
❑ low back	❑ hand/finger/ thumb	❑ ankle
❑ sacrum/pelvis	❑ hip/groin	❑ foot/toe
❑ shoulder/clavicle		

5. Side of body injured: ❑ left ❑ right ❑ bilateral ❑ not applicable

6. Type of injury:

❑ concussion (with or without loss of consciousness)	❑ sprain/ ligament injury	❑ haematoma/contusion/ bruise
❑ structural brain injury	❑ lesion of meniscus, cartilage or disc	❑ abrasion
❑ spinal cord compression/ transection	❑ muscle rupture/ strain/tear/cramps	❑ laceration
❑ fracture	❑ tendon injury/ rupture/ tendinopathy/ bursitis	❑ nerve injury
❑ other bone injury		❑ dental injury
❑ dislocation/subluxation		❑ visceral injury

❑ other injury (please specify): ....

7. Diagnosis of injury (text or code): ....

8. Has the player had a previous injury of the same type at the same site (i.e. this injury is a recurrence)?

❑ no ❑ yes

If YES, specify date of player's return to full participation from the previous injury: ....

9. Was the injury caused by: ❑ overuse ❑ trauma?

10. Did the injury occur during: ❑ training ❑ match?

11. Was the injury caused by contact? ❑ no ❑ yes

If YES, specify the activity: ❑ tackled ❑ tackling ❑ maul ❑ ruck ❑ lineout ❑ scrum ❑ collision ❑ other

12A. Did the referee indicate that the action leading to the injury was a violation of the Laws?

❑ no ❑ yes

12B. Did the referee indicate that the action leading to the injury was dangerous play (Law 10.4)?

❑ no ❑ yes

Figure 1 An injury report form for rugby union.

For studies on rugby union that record team match exposure, the total match exposure time of players in hours for a team is given by $N_M P_M D_M/60$, where N_M is the number of matches played, P_M is the number of players in the team (normally 15) and D_M is the duration of the match in minutes (normally 80 min).

REPORTING DATA

The RICG endorsed the view that the incidence of match and training injuries should be reported separately; in addition, injury profiles should be reported separately for match and training injuries. If the times of match injuries are recorded, the injuries should be grouped into quarters, which would normally be first half: 0–20, 21–40+; second half: 41–60, 61–80+ min. When available, the official match clock time should be used for recording the time of injury.

CONCLUSIONS

The definitions and methodology presented in the consensus statement for football were generally found to be appropriate for rugby union. Minor variations in some definitions and procedures were required, however, to reflect specific issues associated with rugby union. The definitions and procedures presented in this consensus statement should improve the quality of data collected and reported in future studies of rugby union injuries. In addition, the adoption of broadly similar definitions and methodologies across sports should enable meaningful inter-sport comparisons of results to be made. Finally, the definitions and methodologies presented in this consensus statement will form the basis for all future studies of injuries supported by the IRB.

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