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SKELETAL DEVELOPMENT AND THE ASSOCIATED RISK OF CATASTROPHIC HEAD, NECK AND SPINE INJURY

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INTRODUCTION

Rugby is a contact sport, characterised by collisions between players. As a consequence, there is always a risk of injury. This risk occurs at all levels of play during both practice and competition. As the game has evolved and become professional, the speed, power and size of the players has increased[5;38;42]. This has filtered down the ranks with schoolboy players being 10 kg heavier now compared to 40 years ago when Craven Week began[12]. Injuries associated with collision sports are almost inevitable. Several studies have analysed these injuries, with the epidemiology and mechanisms being fairly well described[5.] The injuries that cause most concern for players, support staff and administrators are the catastrophic head, neck and spine injuries which have a devastating effect on the player and his immediate family, who have to deal with the consequences of having to care for a disabled person. The number of players who sustain these types of injuries is not insignificant. Consider that since 2001, eight rugby players in South Africa have died as a result of head injuries and eight players have died as a result of spinal cord injuries. The details of the other catastrophic injuries are shown in Table 1.

Table 1: Number of catastrophic injuries in South African rugby since 2001[53]

CATASTROPHIC INJURY	NUMBER OF PLAYERS
DEATHS	
• head injuries	8
• spinal cord injuries	8
ACUTE SPINAL CORD INJURIES	
• quadriplegia	29
• neurological defects	8
• recovered	69
SERIOUS HEAD INJURIES RESULTING IN DISABILITIES	2

As a consequence of these catastrophic injuries, rugby administrators continually assess and adjust the laws where necessary, with the goal of reducing the risk of injury[4;7;19;21;36]. The most noticeable law change was regarding the engagement in the scrum, which was controlled to reduce the impact of the high forces when the opposing front-row forwards made contact. This law change had a noticeable outcome; in particular, the incidence of potentially catastrophic head, neck and spine injuries were reduced[7]. Another example is the law regarding the so-called 'spear' tackle, which is very strictly controlled by referees: any player who executes a spear tackle is dealt with by being sent off the field, after which he usually receives a suspension. Further examples of law changes and the impact on injuries will be presented later.

As schoolboy rugby becomes more competitive the incentive to have bigger, stronger players increases. This results in two possible scenarios for smaller players. The first scenario is that smaller, but talented players will choose not to play rugby and gravitate to other sports which are not so dependent on size for success. It is very likely that much talent will be lost to rugby through this option. Some players in this group may be late developers, who possess superior skills associated with success in rugby. If these players are not managed appropriately, their superior skills may not ever have an opportunity to manifest and develop fully. The second scenario is that the smaller players may choose to play rugby but will always be at an increased risk of injury because they will be playing against boys who are bigger and stronger. This raises questions on whether the game needs to be managed differently to cater for these smaller players and in particular the wide range of size which exists in rugby players during the pubertal years. Before administrators can make evidence-based decisions about appropriate management to cater for these questions, there needs to be an understanding of the biology of development and growth, particularly of the musculoskeletal system. Different phases of growth need to be related to injury, particularly catastrophic injuries. This will identify whether there are any phases during musculoskeletal development that are associated with a particularly high risk of injury. In accordance with this, the next section will discuss the development of the musculoskeletal system. This will be followed by a section on the risk of injury at different age groups to determine whether there is any age group that has a particularly high risk of injury, and whether this can be related at all to the changes in the musculoskeletal system. The final section will include recommendations for management, based on this evidence.

SKELETAL DEVELOPMENT

Growth starts during conception and continues for about 20 years after birth. By the age of two, boys have achieved nearly 50% of their adult height and by the age of nine this figure rises to about 75%. Just before puberty they are approximately 90% of their adult height[52]. During fetal growth the long bones are laid down as cartilage and before birth the cartilage starts converting into bone, starting from the centre of the bone[52]. These regions are called the primary centres of ossification. Just before birth the secondary centres of ossification occur at the end of the long bones - these are called epiphyses. Centres of ossification can also appear in other areas of the skeleton until the stage of puberty. Cartilage cells in the growth plate, immediately beneath each epiphysis, divide and are passed into the growth plate region and extend into the shaft of the bone. The long column of cartilage cells are converted into bone. It is therefore accurate to say that a limb bone grows inwards from the ends[52]. As the bone grows, the growth plate gets progressively thinner, reaching a stage when the epiphyses are closed, or fused. At this stage no further growth in the long bones is possible[52].

The growth of the width of limb bones occurs independently of cartilage, with new layers of bone being deposited on the outside of existing bone[52]. Throughout growth there is continual remodeling of the bone, with some areas being broken down and absorbed while other areas have bone deposited. The breaking down/deposition is balanced to ensure that the integrity of the bone is maintained. The reshaping is dependent to a large degree on the stresses and strains imposed on the bone by the muscles as well as by gravity.

The bones of children are relatively flexible and compliant because the rate of deposition and absorption occurs at a rapid rate, in contrast to the bones of older adults which become relatively weak and brittle as a result of the imbalance between absorption and deposition[52].

The rate of growth is fastest in a newborn (about 24 cm/year) and this rate decreases progressively from birth to about 5 cm/year just before puberty. At this point, the rate of growth once again increases to about 7 cm in the first year, 9 cm in the second year and then reduces to about 7 cm in the third year of puberty. The rate then decreases progressively, stopping in the late teens. The rate of growth from birth to puberty is shown schematically in Figure 1.

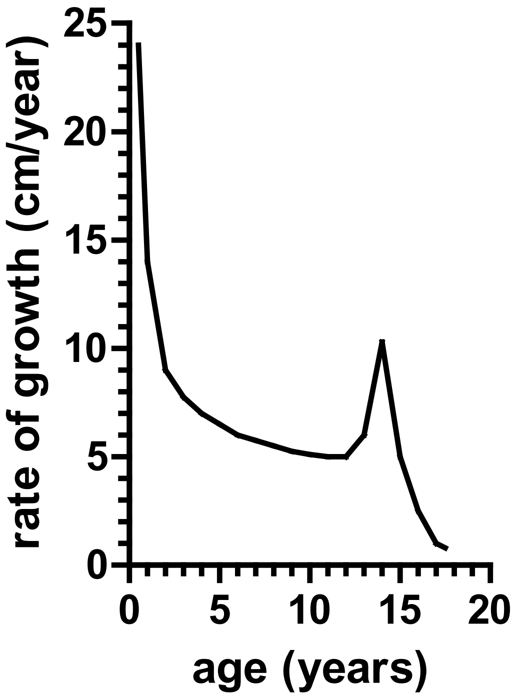

Figure 1: *A typical growth curve for height in boys (redrawn from Foetus into Man: Physical Growth from Conception to Maturity[52])*

The age of the growth spurt coinciding with puberty depends on the population and the circumstances in which that population lives[14]. The rate of growth is not in complete synchrony as most of the spurt in height can be attributed to the acceleration in growth of the trunk rather than from growth of the legs. The growth spurt of the leg length usually occurs about 9 months ahead of the growth spurt in the trunk[52].

During the pubertal years there is a window period of about 3 to 4 years that is sometimes referred to as the 'critical years'. During this period a greater proportion of bone mineral accrual occurs in the bones compared to other periods to growth and development. A cross-sectional study showed that about 35% of total body and lumbar spine peak bone mineral accrual, and 27% of general neck bone mineral accrual, was deposited during the four years around peak height velocity[1]. A longitudinal study showed that the age of peak height velocity preceded the age of peak mineral bone accrual by more than six months[2]. This is important as the gap between peak height velocity and peak mineral bone accrual may represent a vulnerable period in which the bone heads are relatively more fragile and prone to injury. This has been used as an explanation for the increased fracture rate which is observed during adolescence[39]. In contrast, the spine of a prepubescent is more resilient to injury and more compliant to traumatic stress compared to the spine of an adult[32]. Furthermore, the immature spine is hypermobile with ligament laxity, shallow facet joints and undeveloped spinal processes[32]. As children grow, the fulcrum of the cervical axis changes. For example, children younger than eight years have maximal mobility at the C1 to C3 vertebra. By the age of 12 years the fulcrum moves to about the C5 to C6 region where it remains through to adulthood. This explains why younger children are at relatively higher risk of upper cervical injury, compared to getting injured further down the spine[32].

Skeletal age is the most accurate method of assessing biological maturity[52]. The skeletal maturity can be defined by the progression of bones into maturity. Although any part of the skeleton can be measured to assess skeletal maturity, the bones of the hand are the most practical and have been used in many different circumstances. The most common method of assessing skeletal maturity uses an x-ray of the left hand and wrist to determine the different stages in bone maturation. There are three different techniques using this method: the Tanner and Whitehouse II (TW2))[51]; Greulich and Pyle method[22]; and Fels method[30]. All techniques have similar reproducibility and are used to predict either the adult height of a child, or to evaluate advanced or delayed growth. An advantage of the Fels method, which makes it more favourable for research, is that it calculates standard errors of estimate which are not provided with the other two methods. Using this technique of assessing skeletal maturity, it has been shown that in a group of elite adolescent soccer players there was a higher incidence of boys who matured earlier than boys who were still maturing[31].

Whilst there are no studies on adolescent rugby players to confirm whether this pattern also occurs in that sport, the fact that elite youth rugby players are heavier and bigger than players of the same age but of a lower level, does suggest that this pattern also occurs in rugby[13].

In summary, this section has shown that the skeletal system might be vulnerable to injury in the form of fractures around the puberty years. This is compounded by the fact that during this time there are large differences in size as players at varying stages of pubertal development play together and against one another. The next section will discuss the general and catastrophic injuries in rugby union and this will be followed by a section on skeletal maturity and risk of injury.

GENERAL AND CATASTROPHIC INJURIES IN RUGBY UNION AND OTHER COLLISION SPORTS

Of all recreational sports, rugby union has a particularly high incidence of head, neck and shoulder injuries[37]. Furthermore, catastrophic injuries have been associated with rugby union for almost as long as the game has existed[40]. The next section examines reports of injury resulting from participation in collision sports in an attempt to determine whether there is evidence showing that a particular age group or category has a higher risk of injury than others. Specifically, the published reports that include schoolboys and/or junior rugby players will be focused on. Reports in the literature either investigate general or catastrophic injuries, but seldom both simultaneously. The data will be therefore be summarised as such in this report.

GENERAL INJURY

"Incidence" is defined as the "occurrence of new cases of disease in a population during a specific time period"[28]. What is most commonly calculated in sports injury epidemiology papers is either incidence rate - the number of incident injuries divided by the athlete exposure time - or clinical incidence - the occurrence of sports injury per total number of athletes. The term "prevalence" is sometimes incorrectly used to describe incidence. For the purposes of this article, the term "incidence" will encompass both incidence rate and clinical incidence.

The incidence of injury, resulting from participation in collision sports, tends to increase with age during school-going years (Figure 2). The three reports represented in Figure 2 are all prospective studies - which produce the highest level of evidence of all scientific literature. The study of rugby union that took place in Scotland (Figure 2a) discovered a significant trend of an increasing incidence of injury with increasing age in schoolboys.

This study incorrectly termed these new injuries "prevalence", where in fact it was a clinical incidence or incidence that was calculated. Three other reports - two from rugby league[20] (Figure 2b) and one in American Football[27] (Figure 2c) - showed a similar increase in the incidence of injury with age. The latter study concluded that increasing age within high school was a significant intrinsic risk factor for injury in American football.

Moreover, the type of injury is also important to note. Bone injuries (dislocations and fractures) are particularly prevalent in adolescents, both in the general population[23] and in those that participate in collision sports such as rugby union, rugby league and American football[11;20;27;29;43]. Specifically, two well-conducted prospective studies in high schools - one conducted in South Africa[43] and the other in America[11] - demonstrated that fractures were the most common injury during the study period. Whether this finding is a result of the vulnerable skeletal system described earlier, or by the fact that the players are getting bigger and stronger remains to be determined.

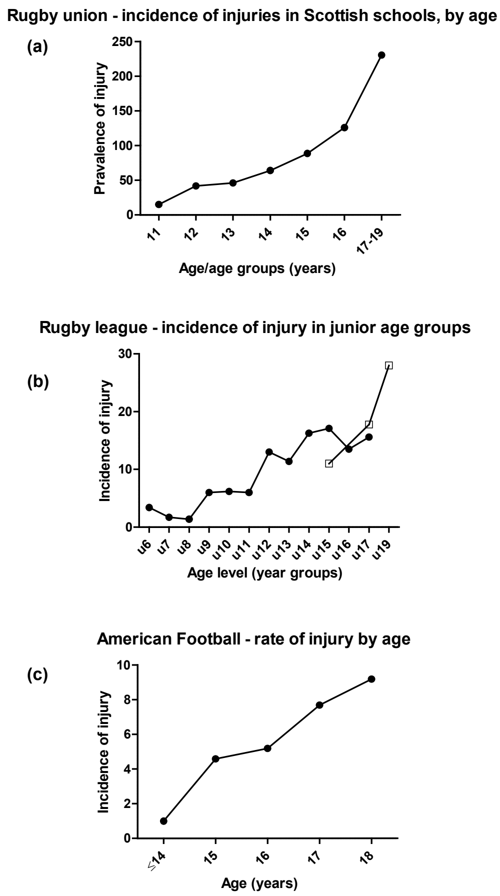

Figure 2. *Incidence of injury, with increasing age in adolescents in (a) rugby union[29] - incidence classified as "prevalence" per 1000 players-seasons, (b) rugby league [20] - incidence classified as number of injuries per 1000-player position hours, and (c) American football[27] - incidence classified as number per 1000 athlete-exposures.*

CATASTROPHIC INJURY

For the purposes of this review and in accordance with the International Rugby Board's (IRB) consensus statement on rugby injury[17] and a recent review on serious injuries[15], catastrophic injury will be defined as "fatalities and brain/spinal cord injuries resulting in significant permanent neurological deficit and which were a direct consequence of playing rugby union". While catastrophic injuries are rare in rugby union in comparison to other sports or recreational pursuits[15;50], they have the greatest permanent effect on both the player and the player's family and community[40].

A series of editorials and comments in medical journals in the late 1970s and early 1980s[10;25;45;48] (Table 1) perpetuated the hypothesis that schoolboys were more at risk of sustaining catastrophic injury than older players. However, it is important to note that all of these claims were opinions of experts stated either in letters or editorials and are not supported by epidemiological evidence.

Table 1. *Anecdotal reports of schoolboys being at risk of catastrophic injury in Rugby Union*

AUTHOR	YEAR	TYPE OF REPORT	QUOTATION	LEVEL OF EVIDENCE
Scher [45]	1979	Letter to editor	*"…serious injuries to the cervical spinal cord are more likely to occur in the younger, lighter, and less-experienced player."*	Anecdotal
Silver[48]	1979	Letter to editor	*"Schoolboys seem to be particularly at risk… ligaments and bones are not so tough at this age and the bones are more easily injured and dislocated than later on."*	Anecdotal
Cervell et al[10].	1983	Letter to editor	*"Adolescent boys, with immature growing cervical spines, are at considerable risk during scrummaging…schoolboys are not always matched with competitors in either size or technique."*	Anecdotal
Horan[24]	1984	Editorial	*"The most vulnerable age for rugby players is between 15 and 21, but the growth in the number of serious injuries in schoolboys is particularly disturbing."*	Anecdotal

In contrast to these early anecdotal reports, a recent review of cervical spinal cord injuries by Quarrie40 concluded that adults have a higher risk of sustaining these injuries while participating in rugby union than adolescents. An examination of retrospective studies confirms, for the most part, that adults comprise the greatest proportion of those suffering a catastrophic injury (Table 2). In most cases the data were not expressed in relation to exposure time or the number of players, and therefore the conclusions should be made with caution. However, with this in mind, these studies show that schoolboys comprised between 9 and 56% of all the reported catastrophic injuries in rugby (Table 2).

Table 2. *Retrospective studies investigating catastrophic injury*

AUTHOR AND COUNTRY	YEARS OF SURVEILLANCE	CLASSIFICATION OF CATASTROPHIC INJURIES	NUMBER OF CATASTROPHIC INJURIES	CATASTROPHIC INJURIES PER YEAR	INCIDENCE OF INJURY/100 000 PLAYERS PER YEAR	PHASE OF PLAY (%)
Burry and Gowland[8], New Zealand	1973-1978*	Permanent or temporary cord compression syndromes	54	9.00	27	-
Noakes et al.[36] South Africa	1990-1997	Did not specify	67 (19% schoolboys)	8.38	-	Tackle (37%)
O'Carrol et al.[37] Ireland	1979-1980	Neck injury severe enough to warrant hospitalisation for ≥ 48 hours.	12	6.00	-	Scrum and ruck (42%)
Kew et al. [26], South Africa	1963-1989	Admission to spinal unit	117 (31% schoolboys)	4.50	-	Tackle (51%)
Carmody et al.[9], Australia	1997-2002	Spinal cord deficit on admission	23	3.83	3.2 (7.2 adults, 0.9 schoolboys)	Tackle (39%)
Bohu et al.[4], France	1996-2006*	Permanently disabling cervical spine injuries (American Spinal Injuries Association Scale A-D), non-fatal.	37 (43% ≤ 21 years of age)	3.36	1.8	Scrum (51%)
Silver [49], U.K	1982-1987	"serious injuries of the spine"	19 (16% schoolboys)	3.17	-	Scrum (39%)
Quarrie et al.[41], New Zealand	1976-2005*	Permanently disabling spinal injury	77	2.57	2.0	1976-2005: Scrum (48%); 2001-5: Tackle (88%)
Wetzler et al. [54], America	1970-1994	Documented fracture or severe ligamentous injury of the cervical spine	59 (51% college or high-school)	2.46	-	Scrum (58%)
Berry et al.[3], Australia	1986-2003*	Acute cervical spinal cord injury resulting in complete/incomplete tetraplegia	32 (9% schoolboys)	1.78	8	Scrum (35%)
Scher[44], South Africa	1964-1976	Complete or incomplete tetraplegia	20 (20% schoolboys)	1.54	-	Tackle (60%)
Shelly et al.[26;47] Ireland	1995-2004	Objective neurological deficit on admission	12 (50% ≤ 19 years of age)	1.20	-	Tackle (67%)
Secin et al.[46], Argentina	1977-1997*	Clinically permanent or transient disabling cervical spine injury	18 (56% ≤ 19 years of age)	0.86	-	Scrum (61%)

** Law changes occurred in response to high incidence of injury: New Zealand (1980 and 1984), Britain (1979, 1984, 1985), Australia (1985) and South Africa (1990)[34].*

Only two retrospective studies, one in Argentina[46] and one in Ireland[47], reported that players younger than 21 years of age had a similar incidence of catastrophic injury compared to older individuals. Other similar studies from South Africa[26;35;36], Australia[54], New Zealand[8] and the United Kingdom[49] showed that adults, or those players older than 21 years of age, had more reports of cervical spinal injuries than younger players. Furthermore, a retrospective study of Australian children younger than 15 years of age participating in rugby league and rugby union concluded that cervical spinal injury was rarely catastrophic in this young group of players[6] .

However, as mentioned previously, data from retrospective studies, as shown in Table 2, should be interpreted with caution. To reach meaningful conclusions about age group and risk, one would have to normalise the number of injuries in a particular age group before comparisons could be drawn as to which group were more at risk. To normalise the data, the exposure time of a particular cohort would have to be known. Either the total exposure time (i.e. training and match time) of the injured athletes or an accurate record of the total number of players participating in a particular sport for a particular sample are required to calculate and compare the incidence of injury[18]. Only when the incidence of injury has been accurately calculated can different populations (i.e. schoolboys vs seniors) be compared for their relative risk of injury. Therefore, the fact that a greater proportion of schoolboys participate in rugby union than seniors in most countries[26] could account for the greater number of these injuries reported in schoolboys and may have led to the impression that this particular age group were at significant risk of catastrophic injury, and therefore prompted the editorials or letters to the editor of journals (Table 1).

Furthermore, law differences between schoolboy rugby (under 19) and open (adult) rugby reduce the comparability of these two populations. Significant and effective changes to under-19 rugby union, occurred as a direct consequence of the flurry of subjective reports referred to in Table 1[34] . Burry and Calcinai[7] attribute a significant reduction in cervical spine injuries to two significant law alterations in New Zealand. Both changes were to reduce "high risk" phases of play: the first change occurred to the maul ("tackled ball") law in 1980 and the second in the scrum in 1985 to reduce its duration and impact (no pushing more than 1.5 m or wheeling of scrum) at junior or schoolboy level. Moreover, Noakes et al.[36] attributed the decline in the incidence and severity of spinal cord injuries in schoolboys to alterations to scrum laws to the under-19 version of the game in South Africa in 1990. These law alterations introduced the "crouch, touch, pause, engage" sequence, which sought to de-power the scrum. Similar reductions in the incidence of cervical spine injuries have also been attributed to scrum law changes in France in 2000-2001[4]. These studies serve as confirmation that comparisons between under-19 and senior versions of game are wrought with irreconcilable errors.

However, there are two good quality reports examining catastrophic injury in France and England which circumvent the intrinsic problem of trying to draw conclusions from the varying conditions of under-19 and open rugby. Both the studies accounted for the number of players in each age group. In France[4], "Junior" age categories (17-21 years of age) had the greatest incidence (5.5/100 000 players per year) of catastrophic cervical spinal injuries - more than either under-17 (0.36/100 000 players) or "Senior" (≥21 years) players (2.42/100 000 players) (Figure 3a). Although this was a retrospective study, an accurate account of the number of players was available for each age category for the years of interest, thereby providing a means of comparison. A prospective study of open (adult) rugby players in the English Premiership[16] found that the youngest age group (19-22 years of age) in the competition were at greater risk of catastrophic injury than any older adult players (Figure 3b). The exact number of players for each age category was also known for this study. These two studies are consistent in their indication that older adolescents/young adults (17-22 years of age) are at greater risk of these injuries than their older playing colleagues.

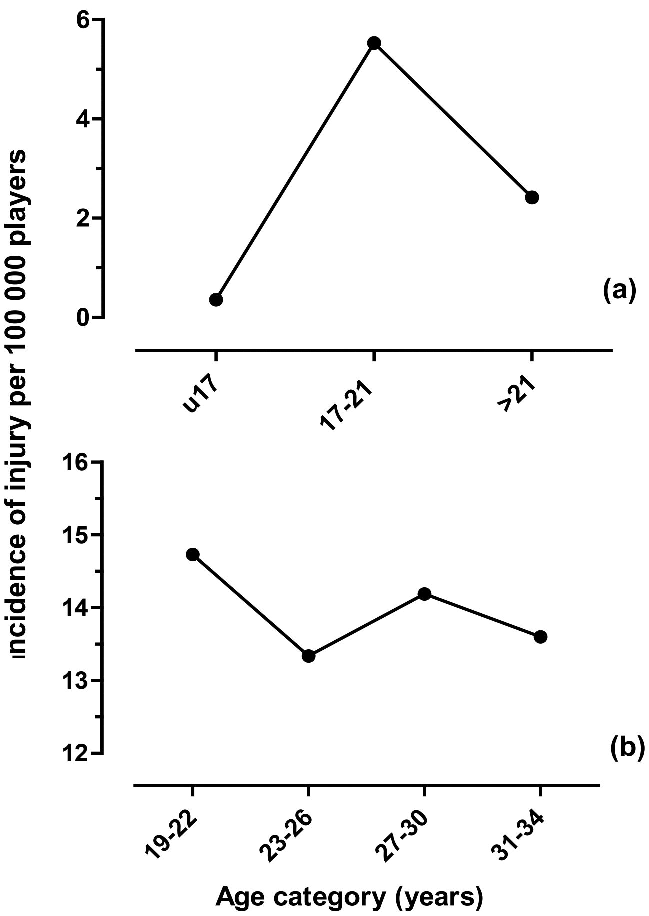

Figure 3. *Incidence of catastrophic injury in (a) French rugby4 and, (b) English Premiership rugby[16].*

MECHANISM OF INJURY

Noakes, in his chapter on spinal cord injuries in rugby players, in the book Rugby without Risk[33] notes that performing a tackle may predispose a player to serious injury, depending on the technique of the tackler. If a restraining force is placed on the top of the head while it is in a lowered position (i.e. for a tackle), the cervical ligaments and vertebrae are at particular risk of injury through hyperflexion. This process is known as "spearing" in American Football terminology and also accounts for a significant proportion of catastrophic injuries in this code[33] . "Spearing" accounts also for the majority of injuries in scrums, and rucks and mauls[33]. The findings of Shelly et al.[47], O'Carroll et al.[37] and Williams and McKibbin[55] concur with the comments of Noakes[33]. Illegal high tackles account almost exclusively for all cervical injuries to the tackled player, which explains why referees are so strict about this particular law infringement[33]. In 2008 and 2009, of the 27 serious and/or catastrophic injuries which occurred in South Africa, 52% resulted from the tackle situation, and 26% from the scrum phase of play[53].

SUMMARY

- schoolboy rugby players are becoming bigger and stronger
- the size difference between the elite and average adolescent player is also increasing
- late developers may be lost to the game if they are not properly managed
- the disparity in body size before, during and after puberty may increase the risk of injury
- the skeletal development during this phase (before, during and after puberty) also imposes an increased risk of injury, particularly bone fractures
- the spinal column of the prepubescent player is more resilient to injury, and more compliant to traumatic stress compared to the spine of adult players
- data suggest that general injuries increase with increasing age in schoolboys/adolescents
- the data on age groups and the associated risk of catastrophic injuries are weak, because most studies do not account for exposure time or the number of players
- the majority of available data are not able to investigate whether schoolboys are at greater risk of sustaining catastrophic injury. More recent reports would appear to suggest that this is not the case
- the 17-22 year age category are more at risk of suffering catastrophic injuries than older players
- most of the catastrophic injuries result from the tackle situation and during scrummaging
- increased safety associated with law changes have reduced the incidence of catastrophic injuries.

RECOMMENDATIONS

- the laws of the games need to be continuously monitored and changed if necessary, as previous law changes have been associated with a reduction in injury
- the existing laws on tackling (high tackles, spear tackles) and scrummaging need to be strictly enforced, as these are the phases of play during which most catastrophic injuries occur
- younger players (i.e. under 19 years) should not be allowed to play with adults, because the undeveloped skeletal structures of the younger players, and the disparity in body size may be associated with an increased risk of injury.

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