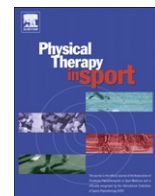




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Lumbar vertebral stress injuries in fast bowlers: A review of prevalence and risk factors

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ABSTRACT

Objectives: To provide a concise overview of the prevalence and risk factors in the development of lumbar vertebral stress injuries in cricketers who are fast bowlers.

Methods: A search of Medline, SPORTDiscus and CINAHL databases was conducted to find relevant studies pertaining to: cricket, cricket biomechanics and lumbar vertebral stress injuries. Narrative review methods were used to synthesise the data.

Results: The prevalence of lumbar vertebral stress injuries in fast bowlers is high, with figures up to 67% reported. Potential risk factors identified include bowling action, overuse, age, lumbar muscle asymmetry and physical characteristics. While prospective studies provide evidence that bowling action and overuse are risk factors for developing lumbar vertebral stress injuries, to date there is limited evidence, largely from cross-sectional studies, regarding the other factors.

Conclusions: This study provides an up-to-date overview of the current literature on prevalence and risk factors for lumbar vertebral stress injuries in fast bowlers. This information may assist clinicians to prevent injury through early identification of risk factors. Recommendations for future research directions include further prospective investigation of the role of age, physical characteristics and muscle asymmetry in the development of such injuries as well as gender specific risk factors.

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1. Introduction

Lumbar vertebral stress injuries can be devastating to an athlete, irrespective of their chosen sport. Sustaining such an injury equates to time away from sport, activity limitations and often, pain (Hardcastle, 1991; Standaert & Herring, 2000). Lumbar spine stress lesions typically occur at the neural arch of the lumbar spine (Cyron & Hutton, 1978), specifically at the pars interarticularis. Such lumbar spine abnormalities also occur in the general population, with variances between races and gender. For instance, prevalence rates for persons of African origin are lower (1–3%) (Roche & Rowe, 1952) than Caucasians (5–7%) (Wiltse, Widell, Jr., & Jackson, 1975), whereas those of Inuit origin display much higher rates (>50%) (Simper, 1986; Stewart, 1953). General studies of the population demonstrate that the prevalence of lumbar vertebral stress injuries in males is double that of females (Amato, Totty, & Gilula, 1984; Beutler et al., 2003). While these defects are often asymptomatic in non-athletic populations (Beutler et al., 2003; Standaert &

Herring, 2000), they may be symptomatic in athletic groups (Standaert & Herring, 2000).

The prevalence of these injuries in athletic populations is higher than in the general community, with figures of 8% (Soler & Calderon, 2000) and 15% (Rossi, 1978) reported. However, prevalence is higher in particular sports (Soler & Calderon, 2000), specifically cricket in which the prevalence for stress lesions in bowlers is between 11 and 67% (Annear, Chakera, Foster, & Hardcastle, 1992; Elliott, Hardcastle, Burnett, & Foster, 1992; Engstrom & Walker, 2007; Foster, John, Elliott, Ackland, & Fitch, 1989; Gregory, Batt, & Kerlake, 2004; Hardcastle et al., 1992; Ranson, Kerlake, Burnett, Batt, & Abdi, 2005), which is higher than most other sports (Annear et al., 1992). Considering the popularity of the game, this high prevalence is cause for concern.

Because the consequences of sustaining a stress lesion may be catastrophic for the career of a fast bowler, it is useful to identify risk factors for these injuries, so that preventative measures may be taken. An earlier study (Elliott, 2000) reviewed risk factors for back injuries. However, the focus was not specifically on bony stress injuries and it was published nearly a decade ago. Since then, new research has been conducted. Thus, the aim of this review was to provide an up-to-date narrative review of research about the

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prevalence of and risk factors for the development of lumbar spine stress lesions in fast bowlers and the prevalence of injury.

2. Methods

2.1. Design: narrative review of the literature

2.1.1. Search strategy

A search of Medline, SPORTDiscus and CINAHL databases was conducted from inception to December, 2010, to find relevant studies pertaining to: cricket, cricket biomechanics, and lumbar spine bony stress injuries, including spondylolysis and spinal fractures. An expert in the field of cricket biomechanics was consulted to determine if any key studies were omitted.

2.1.2. Definition of lumbar bony stress injury

There are discrepancies in the literature about the definition of a lumbar bony stress injury. Many studies limit the definition to spondylolysis or spondylolisthesis (Gregory et al., 2004; Hardcastle et al., 1992). Other authors advocate the inclusion of pedicle sclerosis to indicate a stress reaction of either the pedicle or pars interarticularis (Annear et al., 1992; Elliott et al., 1992). For the purposes of this review, a bony stress injury was defined as an injury displaying the abnormal radiographic signs of spondylolysis, spondylolisthesis or pedicle sclerosis.

2.1.3. Data extraction and analysis

Data regarding the prevalence of lumbar bony stress injuries and risk factors in cricketers were extracted. Narrative review methods were used to synthesise the data and a descriptive analysis of the data conducted.

3. Results and discussion

3.1. Included studies

The search yielded 440 studies (268 in Medline and 172 in SPORTSDiscus and CINAHL), of which 85 were unique and relevant to the study and included in the review. Throughout the review additional sources were sought to clarify issues. Many studies were cross-sectional in design, limiting causal inference regarding risk factors. Prospective studies were primarily used to extract risk factor data. Experimental studies were also included to examine the anatomical and biomechanical risk factors associated with stress lesions.

3.2. The nature of lumbar bony stress injuries in cricketers

Current opinion is that bony stress injuries occur to the pars interarticularis in fast bowlers, because the structure is vulnerable to damage from repetitive lumbar flexion, rotation and hyperextension (Elliott, 2000), which are common movements in bowling. The anatomy of the neural arch and the narrowness of the pars interarticularis further increase the risk of injury (Farfan, Osteria, & Lamy, 1976; Lamy, Bazergui, Kraus, & Farfan, 1975). These injuries in fast bowlers occur bilaterally as well as unilaterally. Some studies report an approximately equal proportion of bilateral and unilateral defects (Hardcastle, 1993; Hardcastle et al., 1992; Millson, Gray, Stretch, & Lambert, 2004; Ranawat, Dowell, & Heywood-Waddington, 2003), whereas others (Elliott et al., 1992; Engstrom & Walker, 2007; Engstrom, Walker, Kippers, & Mehnert, 2007; Gregory et al., 2004) report a greater proportion of unilateral injuries, particularly at the levels of L4 and L5. It is interesting to note that almost all unilateral lesions are found contralateral to the player's bowling arm. Some authors (Ferdinands, Kersting, &

Marshall, 2009; Ranson, Burnett, King, Patel, & O'Sullivan, 2008) suggest this pattern of injury may be due to the large stresses applied to the lumbar vertebra during active lateral bending of the spine away from the bowling arm during the bowling action. This loading of the lumbar spine may be accentuated by certain biomechanical factors, as forces are applied to the spine as it reaches end of range during the act of bowling (Ferdinands et al., 2009), especially contralateral side-flexion away from the bowling arm (Ranson et al., 2008).

Bony stress injuries in sportspeople typically occur in the lumbar spine at the level of L5 (Standaert & Herring, 2000). This has been shown in numerous studies, most notably in a large prospective study of American footballers (McCarroll, Miller, & Ritter, 1986) where 70% of stress fractures occurred at the level of L5. Conflicting results have been found in cricket, with two studies reporting similar results to those above (Gregory et al., 2004; Millson et al., 2004) while others report more injuries at L4 (Engstrom et al., 2007; Ranson et al., 2005). However, it is widely accepted that L5 is most susceptible to a bony injury, due to the relatively quick changes in direction that can occur between the spine and the pelvis (Cyron & Hutton, 1978) and because of the high forces transmitted through a structure inherently unstable (Eisenstein, 1978) and anatomically weak (Chosa, Totoribe & Tajima, 2004). These findings are especially relevant to cricketers, as these biomechanical factors are features of certain bowling styles.

3.3. Incidence and prevalence of lumbar spine stress fractures in cricketers

There are few reports of the incidence of lumbar spine stress fractures in the cricketering population. Only two studies were found in this review. The 2008 Cricket Australia Injury Report (Orchard, James, Kountouris, & Portus, 2008) investigated injury incidence in national and state teams between 1998 and 2008. The investigators found the average incidence of lumbar spine stress fractures was 0.61 injuries per team per season. This indicates that in elite Australian cricketers, which includes 7 teams and accounts for around 210 players each year, approximately 4.3 players will be diagnosed with a lumbar stress fracture annually. A prospective study of fast bowlers specifically reported an incidence rate of 24% (Engstrom & Walker, 2007). It would be useful for incidence data to be collected in the future as they are useful to monitor the effectiveness of preventive interventions.

Many more studies have investigated the prevalence of bony stress lesions in fast bowlers. These data, summarised in Table 1, show that fast bowlers have an unusually high prevalence of up to 67%, compared with the general population, in which the prevalence is about 6% (Beutler et al., 2003; Wiltse et al., 1975). An early study (Foster et al., 1989) found that 11% of fast bowlers showed radiographic features consistent with either spondylolysis or spondylolisthesis. Other cross-sectional studies report higher prevalence figures ranging from 45 to 67% (Annear et al., 1992; Gregory et al., 2004; Hardcastle et al., 1992). Overall, these figures indicate that the prevalence of these injuries is disproportionately high in fast bowlers when compared with the general community and other athletes (Annear et al., 1992; Engstrom & Walker, 2007).

3.4. Impact of injury on bowlers

One of the main impacts of a lumbar bony stress injury on a fast bowler is time away from sport. Clinicians advocate a minimum rest period of 2–3 months (Engstrom & Walker, 2007) although most cricketers take 6–12 months to return to play after seeking treatment (Debnath et al., 2007). For those who remain symptomatic, surgery may be indicated (Hardcastle, 1993). The outcomes

Table 1
Prevalence of lumbar vertebral stress injuries in fast bowlers.

Author	Population	Mean age (years)	Number of subjects (n)	Bony abnormalities (%) ^a	Spondylolysis (%)	Spondylolisthesis (%)	Pedicle Sclerosis (%)
Annear et al., 1992	Former state fast bowlers	48	20	NR	33	10	30
Elliott et al., 1992	West Australian fast bowlers	18	20	55	20	25	30
Engstrom and Walker, 2007	Club and international fast bowlers	NR	51	24	22	2	NR
Foster et al., 1989	Elite young fast bowlers	17	82	NR	11	NR	NR
Gregory et al., 2004	Amateur and professional cricketers	20	42	NR	67	NR	NR
Hardcastle et al., 1992	West Australian fast bowlers	18	22	54	36	18	NR
Ranson et al., 2005	Professional fast bowlers	26	36	53	NR	NR	NR

^a Bony abnormalities are defined as abnormal radiographic features demonstrating a stress reaction (can include spondylolisthesis, spondylolysis or pedicle sclerosis). NR = not reported.

from surgery, particularly return to sport, are variable and it may take up to 2 years before players can return to cricket (Debnath et al., 2007).

Pain, surprisingly, may not be the main problem for cricketers with such injuries. Aligning with other imaging studies of the spine, recent research (Millson et al., 2004) shows there is a low correlation between pain and radiographic features of lumbar vertebral stress injuries. For example, one study described fast bowlers who had radiographic signs of a pars lesion but were asymptomatic and able to bowl pain-free (Millson et al., 2004). One interpretation of these findings is that the condition may be painful during the stress reaction stage (grade 1–3) but not once the injury has progressed to incorporate the cortical bone (grade 4) (Millson et al., 2004). This hypothesis is supported by other investigations (Ranson et al., 2005) of cricketers who have spondylolysis but are asymptomatic. If this is the case, pain may impact most on the cricketer in the early stages of injury. However, this research contradicts findings from other sporting populations (Standaert & Herring, 2000), suggesting that this phenomenon may be peculiar to fast bowlers. This has important implications for clinicians as pain may not be a reliable outcome measure for determining return to play status (Millson et al., 2004).

An alternative and controversial theory is that pars interarticularis stress fractures are an unavoidable and possibly advantageous physiological adaptation to fast bowling (Millson et al., 2004). The hypothesis is that these fractures assist the cricketer to avoid future mechanical pressure on the vertebra, and avoid pain. However, as stress fractures may diminish the level of spinal stability (Hardcastle, 1993) and have other adverse effects on overall spinal function, the validity of this theory is uncertain.

Despite the poor association between pain and injury, much research on the impact of a stress lesion on an athlete focuses on pain. However, injury recurrence and the development of comorbid conditions are also important potential consequences. It can be speculated that these injuries impact on other aspects of players' lives, such as mood, sleep and quality of life, although this has yet to be investigated. This may be one area where further research may need to be conducted in order to gain a complete picture of the impact of this condition, so that treatment may be tailored accordingly.

3.5. Risk factors for lumbar vertebral stress injury

3.5.1. Bowling actions

The predominant theory in current literature is that particular bowling styles place an individual at higher risk of a lumbar vertebral stress injury (Annear et al., 1992; Elliott & Khangure, 2002; Elliott et al., 1992; Foster et al., 1989; Hardcastle et al., 1992). A brief review of the classification of bowling styles is necessary in order to understand the different actions. Classification of bowling action has been conducted by traditional means as reported in the literature (Bartlett, Stockill, Elliott, & Burnett, 1996;

Portus, Mason, Elliott, Pfitzner, & Done, 2004). Newer studies (Ferdinands, Kersting, Marshall, & Stuelcken, 2010; Ranson et al., 2008) have advocated for a simplified and more specific method of classification. This study has employed the older terms of classification, as most studies incorporated in this review have also utilised these definitions.

3.5.1.1. Side-on action. The side-on technique (Fig. 1) is typically characterised by a low run-up speed, rear-foot positioned parallel with the popping crease, and a shoulder alignment at rear-foot strike that points down the wicket towards the batter at



Fig. 1. Side-on bowling action, from back foot contact. A: side view, B: front view. Images generously provided with permission by Sports & Spatial Services Pty Ltd and Quintic Consultancy Ltd (UK).

approximately 180° (shoulder segment angle) (Bartlett et al., 1996). Thus, the fast bowler has the appearance of bowling 'side-on' as they begins the delivery stride, with the left hip and shoulder (for a right hand bowler) pointing towards the batter. A recent classification of bowling actions (Portus et al., 2004) describes the side-on action as "a shoulder segment angle less than 210° at back foot contact, a hip-shoulder separation angle less than 30° at back foot contact, and, shoulder counter-rotation less than 30° " (p.266) (Portus et al., 2004). A key feature of a side-on delivery is that the lumbar spine is subject to less rotation when compared with other actions. The side-on action while being the most 'traditional' action is now considered to be extremely rare in modern day fast bowlers (Ferdinands et al., 2010; Ranson et al., 2008).

3.5.1.2. Front-on action. The front-on action (Fig. 2), made famous by the West Indian pace bowlers throughout the 1970s and 1980s (Hardcastle, 1991), has been adopted widely in the modern game (Ferdinands et al., 2009). In a front-on action, the bowler's hips and shoulders are open prior to delivery, giving the appearance of the bowler running straight towards the batter. This action is described as "having a shoulder segment angle greater than 240° at back foot contact, a hip-shoulder separation angle less than 30° at back foot contact, and, shoulder counter-rotation less than 30° " (Portus et al.,

2004). As with the side-on action, the degree of rotation of the lumbar spine is less than in other actions.

3.5.1.3. Semi-open action. This sub-classification is relatively new and was advocated as a safe technique by the Australian Cricket Board as recently as 1998 (Portus et al., 2004). In this action (Fig. 3), the shoulder segment angle lies between the front-on and side-on actions. Similar to both the side-on and front-on actions, there is little to no counter-rotation of the shoulders. It is described as "a shoulder segment angle from 210 to 240° at back foot contact, a hip-shoulder separation angle less than 30° at back foot contact, and, shoulder counter-rotation less than 30° " (Portus et al., 2004).

3.5.1.4. Mixed action. The mixed action (Fig. 4) is a combination of both the front-on and side-on bowling actions, therefore the exact technique can vary. For instance, when the back foot makes contact, the hips and lower limb can adopt an orientation consistent with a side-on action whereas the shoulders face front-on to the batter, but the opposite of this can also occur. The mixed action is defined as any action with "a hip-shoulder separation angle equal to or greater than 30° at back foot contact, or, shoulder counter-rotation equal to or greater than 30° " (Portus et al., 2004). Recent studies (Ferdinands et al., 2010; Ranson et al., 2008) employing more

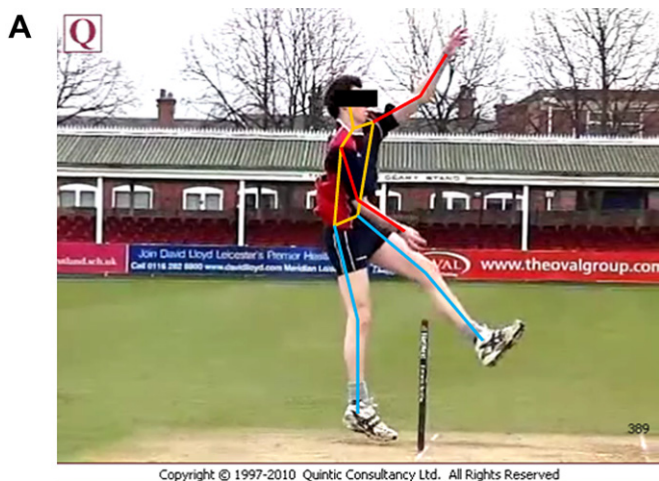


Fig. 2. Front-on bowling action, from back foot contact. A: side view, B: front view. Images generously provided with permission by Sports & Spatial Services Pty Ltd and Quintic Consultancy Ltd (UK).

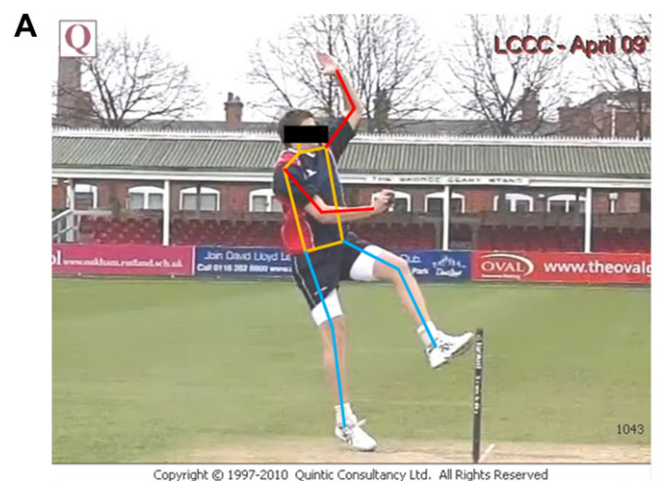


Fig. 3. Semi-open bowling action, from back foot contact. A: side view, B: front view. Images generously provided with permission by Sports & Spatial Services Pty Ltd and Quintic Consultancy Ltd (UK).



Fig. 4. Mixed bowling action, from back foot contact. A: side view, B: front view. Images generously provided with permission by Sports & Spatial Services Pty Ltd and Quintic Consultancy Ltd (UK).

specific classification methods, have identified that this action is the most prominent in professional adult bowlers from England, Australia and New Zealand (Ferdinands et al., 2010; Portus et al., 2004; Ranson et al., 2008).

3.5.2. Bowling actions and injury risk

3.5.2.1. Mixed action. The mixed action has been found in numerous studies to be strongly associated with the development of lumbar vertebral stress injuries (Annear et al., 1992; Elliott, Hardcastle, Khangure, & Burnett, 1993; Elliott et al., 1992; Foster et al., 1989; Portus et al., 2004). In a recent study of fast bowlers (Portus et al., 2004), 89% of players diagnosed with a bony stress injury bowled with a mixed action. Until recently, the main factor has been thought to be the large degree of shoulder counter-rotation in this action (Elliott et al., 1992; Elliott et al., 1993; Foster et al., 1989; Portus et al., 2004). New research (Ranson et al., 2008) questions the importance of shoulder counter-rotation as a causative factor of stress injuries in the adult fast bowler. Instead, the hypothesis is that senior fast bowlers may experience undue stress on the pars interarticularis during their delivery stride due to the large contralateral lumbar side-flexion motion coupled with large ground reaction forces. This theory is supported by other evidence (Chosa et al., 2004) that stresses on the pars interarticularis are

greater with loading and contralateral flexion as opposed to loading and rotation alone, although this has not yet been linked to a particular bowling action.

3.5.2.2. Front-on, semi-open and side-on actions. There is no evidence for an increased risk of injury with front-on and semi-open actions, most likely due to the lower levels of counter-rotation associated with this bowling style. The front-on action is favoured by West Indian cricketers (Hardcastle, 1991). Because rates of spondylolysis and spondylolisthesis are lower in those of African origin (Roche & Rowe, 1952) it is possible that this action is not entirely risk free, but rather one used by a population that has genetic resilience to lumbar bony stress injuries.

The side-on action has traditionally been advocated as the 'correct' way to bowl (Bartlett et al., 1996). It was only in 1994 that the coaching manual from the Marylebone Cricket Club considered the international coaching reference standard, acknowledged any other bowling techniques (Bartlett, 2003). The fact that side-on actions have been traditionally coveted by cricketing authorities may have led to some cricketers with a front-on technique to develop the potentially injurious mixed technique, as coaches encourage their bowlers to bowl side-on (Bartlett, 2003). Accordingly, more coaches are now focusing on developing the front-on, side-on or semi-open bowling style and discouraging the use of the mixed technique. A further consideration is that ball speed is similar for all actions (Elliott & Foster, 1984). Therefore, bowling performance may not be adversely effected by changing from a mixed action to a lower risk action. The clinical implications are that screening and technique correction for bowling are viable prevention options that may be tolerated by the bowler if performance is unlikely to be affected.

In addition to the type of bowling action, other factors associated with bowling style have been postulated as playing a role in the development of a stress lesion. These include a greater height of ball release, relative to the height of the bowler, and extension of the front knee during delivery (Elliott et al., 1992; Foster et al., 1989), however, these factors require further exploration.

3.5.3. Lumbar spine muscle morphology

One potential risk factor that has been more recently investigated is spinal musculature asymmetry, particularly of the quadratus lumborum muscles (Ranson, Burnett, O'Sullivan, Batt, & Kerlake, 2008). Muscle asymmetry has been reported (Engstrom, Walker, Kippers, & Buckley, 2000; Engstrom et al., 2007; Hides, Stanton, Freke, Wilson, McMahon, & Richardson, 2008; Ranson et al., 2008) but only two studies have investigated the link with lumbar vertebral stress injuries (Engstrom et al., 2000; Engstrom et al., 2007). One preliminary study (Engstrom et al., 2000) showed a strong association between an increased quadratus lumborum muscle volume (>10%) on the dominant arm side and developing a lumbar vertebral stress injury at the L4 level (relative risk: 4.0). A later prospective study (Engstrom et al., 2007) investigated the development of symptomatic pars lesions and quadratus lumborum asymmetry in 56 male fast bowlers aged 13–17 years, over four years. During the period of the study, 11 bowlers acquired a pars lesion, all at L4. All 11 bowlers had larger quadratus lumborum muscles on their dominant bowling arm side. The asymptomatic bowlers also had asymmetries, as has been shown in other studies (Ranson et al., 2008), but to a much lesser extent. This study demonstrated that bowlers with a quadratus lumborum asymmetry of 25% or more, have a 58% (95% CI: 32%, 80%) probability of developing a pars lesion. In contrast, the risk is 4% (95% CI: 0.01%, 17%) in those with a muscle asymmetry of 5% or less (Engstrom et al., 2007). The theory underlying this increased injury risk is that quadratus lumborum asymmetry increases the shear

loading of the pars interarticularis (Engstrom et al., 2000; Engstrom et al., 2007), although direct evidence for this hypothesis is lacking.

An opposing hypothesis is that quadratus lumborum asymmetry may actually reduce the amount of stress applied to the lumbar spine. Using mathematic musculoskeletal modelling (de Visser, Adam, Crozier, & Pearcy, 2007), it has been proposed that asymmetrical hypertrophy may in fact be a protective mechanism, acting to control the large side-flexion moment during the bowling delivery occurring on the contralateral side to the delivery arm (Ranson et al., 2008).

Although there appears to be a strong correlation between quadratus lumborum asymmetry and the prevalence of pars interarticularis lesions, it remains unclear whether asymmetry plays a causative role in the development of the lesion. If the lumbar spine modelling is correct, asymmetry may be a reactive measure to other predisposing factors. Further research is needed to clarify these issues.

3.5.4. Physical characteristics and conditioning

Although not widely investigated, there are possible links between intrinsic physical characteristics of the bowler and developing a lumbar vertebral stress injury. One prospective study found that one physical variable associated with increased risk of lumbar vertebral stress injury is a low medial longitudinal arch of the foot (Foster et al., 1989). The authors hypothesised that this characteristic may lead to ineffective force dissipation through the lower limb, which is then transmitted to the lumbar spine. This theory is supported by other data (Elliott, 2000).

Other physical characteristics of the player have not been definitively linked to the incidence of stress injuries, although the results of some studies warrant further investigation. For instance, there is anecdotal evidence that tight hamstrings and an excessive lordotic posture may play a role in the development of a stress lesion (Brukner, Kahn, & Press, 2006; Standaert & Herring, 2000). The association of poor hamstring and lumbar spine flexibility with inter-vertebral disc abnormalities has been demonstrated (Elliott et al., 1992), but no study has linked these factors with stress lesions. It is possible that poor flexibility and general conditioning play a role in the development of injury (Finch, Elliott, & McGrath, 1999), although these associations need to be clarified.

3.5.5. Overuse

Overuse has been considered a risk factor for the development of bony stress reactions, particularly in the lumbar spine for some time (Bell, 1992; Brukner et al., 2006). Early cadaveric studies involving repetitive mechanical loading of the pars interarticularis (Cyron & Hutton, 1978) demonstrated that this area of the neural arch is vulnerable to bone stress, fatigue and eventual failure. Two studies (Dennis, Finch, & Farhart, 2005; Foster et al., 1989) have shown a relationship between overuse and lumbar vertebral stress injuries in fast bowlers. In one study, 59% of players who bowled in greater than 17 matches sustained either a stress lesion or a muscular injury, although the specific proportion of stress injuries was not reported. The other prospective study of junior fast bowlers (Dennis et al., 2005) provides good evidence that high bowling workloads increase the risk of injury. Compared with bowlers who had an average of more than 3.5 rest days between bowling, bowlers who had an average of less than 3.5 rest days were at a significantly increased risk of injury (risk ratio (RR) = 3.1, 95% confidence interval 1.1 to 8.9). Lumbar vertebral stress injuries accounted for 11% of the total injuries in this cohort (Orchard, James, Alcott, Carter, & Farhart, 2002).

Other studies have linked abnormal spikes in bowling workload with an increased likelihood of injury 3–4 weeks later (Orchard, James, Portus, Kountouris, & Dennis, 2009). These authors

speculated that after a peak of overuse, new repair tissue is laid down and 3–4 weeks later this tissue is too immature to cope with the stresses applied to it during normal bowling workloads. This study found moderate correlations between overuse and soft-tissue injuries, although the correlation between overuse and lumbar stress injuries was weaker.

Abnormally high bowling workloads during matches may also have immediate effects on the risk of sustaining a lumbar vertebral stress injury, because the bowling action may change due to player fatigue. Portus et al. (Portus, Sinclair, Burke, Moore, & Farhart, 2000) demonstrated that during an 8-over spell of fast bowling, the high risk component of shoulder counter-rotation increased throughout the spell. This has important implications for training modification, as injury risk may increase with overuse and fatigue. To address this issue, some cricket bodies have developed guidelines to restrict the number of overs bowled, especially for young cricketers (Finch et al., 1999).

The existing evidence for overuse as a risk factor for the development of a lumbar vertebral stress injury indicates that this area deserves further attention. In particular, continued research is needed to provide scientific evidence for bowling workload guidelines for fast bowlers.

3.6. Age

High injury rates are found in younger bowlers (Stretch, 1995). However, most studies investigating lumbar bony stress injuries in fast bowlers use a relatively young study cohort, (Engstrom & Walker, 2007; Engstrom et al., 2000; Engstrom et al., 2007; Foster et al., 1989; Hardcastle et al., 1992; Hardcastle, 1993) so it is possible that there is subject bias regarding age as a risk factor from these studies. However, there are experimental biomechanical data (Cyron & Hutton, 1978; Farfan et al., 1976) demonstrating that the spines of those under 20 years are at increased risk of injury. During repetitive mechanical loading of cadaveric vertebral samples, spines aged between 14 and 30 years showed the greatest susceptibility to fracture through the pars interarticularis (Cyron & Hutton, 1978). This study also showed spines from subjects less than 20 years of age were weaker than spines from older subjects. These authors theorised that as inter-vertebral discs are more elastic in younger spines, greater shear forces reach the articular facets placing greater stress on the neural arch. A further consideration is that ossification of the neural arch may not be complete until the age of 20, placing the structure at further risk. This view is supported by others who consider the underdevelopment of the pars interarticularis (Hardcastle, 1991) and lumbar transverse processes (Farfan et al., 1976) of the adolescent vertebra predisposes younger players to an increased risk of developing a spondylolysis.

Further mediating the age-related anatomical differences in susceptibility to lumbar bony stress injuries may be the biomechanical impact of different bowling styles. Ranson et al. (2008) have suggested that excessive contralateral trunk side-flexion coupled with large loading may cause bony stress injuries in adult (>20 yr) fast bowlers. However in adolescent fast bowlers, a high degree of shoulder counter-rotation (possibly due to poor technique) may be a specific factor increasing the risk of injury in these younger players (Ranson et al., 2008).

From this evidence, the theory that younger age is a risk factor for the development of a stress injury seems plausible. Although there are no prospective studies that explicitly link adolescence with an increased risk of injury, the anatomical and experimental evidence indicate that these younger spines may well be at risk. While not a modifiable risk factor, those of younger age may benefit from targeted preventive interventions to correct technique and reducing

workload. Indeed, some cricketing bodies have implemented strategies to reduce younger cricketers' exposure to bowling.

3.6.1. Gender

We were unable to locate any published studies on lumbar vertebral stress injuries in female bowlers. There are, however, some data about self-reported back pain available from a retrospective study of trunk kinematics in 26 elite Australian female fast bowlers (Stuelcken, Ferdinands, & Sinclair, 2010). The prevalence of back pain in this cohort (54%) was similar to the prevalence of stress lesions in male fast bowlers (Table 1). The authors found that elite female fast bowlers were equally as likely to use a mixed bowling action as males. The key feature that distinguished female bowlers with and without back pain was a large lateral flexion angle in the bowling action, and not shoulder counter-rotation.

4. Conclusions

This review has identified certain factors that may predispose a cricket fast bowler to lumbar vertebral stress injury. Bowling actions such as the mixed action appear to be strongly associated with an increased risk of developing stress lesions in the lumbar spine, especially in adolescent populations. Current evidence suggests that for adult bowlers, excessive contralateral lumbar side-flexion, rather than shoulder counter-rotation, is the key variable in the mixed action that increases the risk of lumbar spine injury. These data indicate that the technique of fast bowlers who use a mixed action should be assessed and retraining provided to reduce the risk of lumbar spine injury. There is moderate evidence that overuse is also an important risk factor for lumbar spine injury, although appropriate workload guidelines have yet to be empirically established. Other factors identified in this review do not have the same strength of evidence. Nonetheless, there is preliminary evidence that younger age (<20 years), may increase risk, thus younger bowlers may benefit from preventive measures. There is uncertainty as to whether lumbar muscle asymmetry, poor physical conditioning, certain physical characteristics or gender may predispose a player to injury. Prospective studies are needed to further investigate these factors.

4.1. Study limitations

Every attempt was made during the writing of this review to include all relevant studies. It is possible, due to the type of search conducted and the databases accessed, that not all pertinent information was captured. Gender bias exists, as no studies of lumbar bony stress lesions in female cricketers were identified. It is unknown if language bias exists in this review, but it is possible as studies in languages other than English were not included.

4.2. Directions for future research

This review has identified five areas for future research to investigate: (1) the association between lumbar muscle asymmetry, other physical characteristics and lumbar bony stress injuries; (2) the relationship between age and injury; (3) thresholds of bowling workloads to avoid fatigue injuries of the spine, (4) stress lesions in female cricketers and (5) injury incidence rates. Future research into risk factors should utilise a prospective design and use sampling methods that ensure representativeness.

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- The authors declare there are no conflicts of interest regarding this work.

Conflict of interest statement

The authors declare there are no conflicts of interest regarding this work.

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