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Multiple risk factors associated with lumbar bone stress injury in youth cricket fast bowlers

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A B S T R A C T

To investigate the relative influence of multiple risk factors on the development of lumbar bone stress injury in a cohort of youth cricket fast bowlers. Injury data from five consecutive cricket seasons was retrospectively reviewed to determine which of a group of 222 high level youth male cricket fast bowlers (age 17.4 ± 1.1 years) sustained a lumbar bone stress injury. This information was then combined with measures related to age, anthropometry, musculoskeletal screening, physical fitness, bowling volume and bowling technique for use in a multivariate binary logistic regression analysis of risk factors for lumbar bone stress. There were 49 lumbar bone stress injuries in the cohort. Multivariate analysis identified a younger age ($p < 0.001$), a taller height ($p = 0.011$), and a faster bowling speed ($p = 0.022$) as significant risk factors for lumbar bone stress injury. The multivariate model was able to explain 36% of the variance (Nagelkerke $R^2 = 0.36$). The risk of injury was 2.99 times higher for every year younger, 1.1 times higher for every centimetre taller, and 1.1 times higher for every km/h faster bowling speed. A younger, taller, faster bowler was the profile for a bowler at increased risk of lumbar bone stress injury in our study. However, it was evident that other factors not included in the current study also play a significant role in the aetiology of a lumbar bone stress injury.

1. Introduction

In the game of cricket, the prevalence of injuries to fast bowlers is approximately three times higher than other players in a team (Orchard, Kountouris, & Sims, 2016). Fast bowlers are particularly susceptible to lumbar bone stress injury (stress reaction (bone oedema with no cortical breach) or stress fracture (bone oedema with cortical breach)), with reported incidence varying between 11-33% (Crewe, Elliott, Couanis, Campbell, & Alderson, 2012; Foster et al., 1989; Kountouris et al., 2019). Lumbar bone stress injury (LBSI) accounts for the greatest time lost to injury in cricketers (Orchard et al., 2016), with recovery periods in the order of 6-8 months (Alway, Brooke-Wavell, Langley, King, & Peirce, 2019; Ranson, Burnett, & Kerslake, 2010). Younger fast bowlers (< 22 years of age) appear to be particularly at risk, being three to four times more likely to suffer a bone stress injury (predominantly lumbar spine) than their older counterparts (Alway, Brooke-Wavell, et al., 2019; Blanch, Orchard, Kountouris, Sims, & Beakley, 2015).

Purported risk factors for LBSI include specific biomechanical factors related to bowling technique such as higher shoulder counter-rotation and trunk lateral flexion (Bayne, Elliott, Campbell, & Alderson, 2016; Portus, Mason, Elliott, Pfitzner, & Done, 2004; Ranson, Burnett, King, Patel, & O'Sullivan, 2008). Higher volumes of bowling are associated with injury (Alway, Brooke-Wavell, et al., 2019; Dennis, Farhart, Goumas, & Orchard, 2003), with the lumbar spine likely susceptible to repetitive loading due to large vertical ground reaction forces (Bayne et al., 2016) and high intervertebral shear forces (Crewe, Campbell, Elliott, & Alderson, 2013) associated with fast bowling.

Physical preparation is considered to be an important component to injury prevention in fast bowlers (Forrest, Scott, Hebert, & Dempsey, 2018), although there is limited evidence linking LBSI to physical deficits. A reduction in sit and reach distance has been identified in youth fast bowlers with disc degeneration (Elliott, Hardcastle, Burnett, & Foster, 1992), and a greater quadriceps torque in the front foot of bowlers who suffered a lumbar spine stress fracture (Foster et al., 1989). A more recent

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prospective study identified a reduction in lumbar extensor muscle endurance and greater medial knee movement in a single leg decline squat in youth fast bowlers who subsequently sustained a low back injury including stress fracture (Bayne et al., 2016). Evidence from predominantly college age female populations suggest excessive medial knee movement during the squat task may be related to hip abduction and external rotation muscle weakness (Cashman, 2012; Powers, 2010; Stickler, Finley, & Gulgin, 2015; Willy & Davis, 2011). Therefore, there may then be a link between hip muscle weakness and the development of LBSI, however to date there is no direct evidence supporting this as a possible risk factor.

The development of LBSI is clearly multi-factorial, yet the majority of published fast bowling injury research has tended to focus on broader risk areas such as workload and technique in isolation. The studies that have looked at multiple risk factors have either had small numbers (Bayne et al., 2016) or did not use multivariate analysis (Foster et al., 1989). This has made it difficult to understand the relative contribution of individual risk factors to the overall injury risk. The aim of this study was to investigate the relationship between LBSI and combinations of risk factors encompassing workload, technique and physical preparedness in youth fast bowlers.

2. Methods

Ethics approval was attained from the La Trobe University Human Research Ethics Committee (HEC20058). Data were retrieved from Cricket Australia's online database (Athlete Management System, Fair Play Pty Ltd.).

2.1. Participants

Two hundred and twenty-two Australian youth male fast bowlers (17.4 ± 1.1 years, range 15.1-19.7) participated in elite pathway programs over five seasons (2015-20, season from July to March). A fast bowler is defined as a bowler who has a fast run up, delivers the ball at a medium-to-fast pace, and to which the wicket keeper typically stands back from the stumps. Bowlers were included if: 1) they were medium-to-fast bowlers as classified by their state cricket program; 2) they were members of their respective state under-17 or under-19 cricket programs; 3) prior to the season had received a musculoskeletal screening; and; 4) had bowling volume recorded; Bowlers who met the inclusion criteria for more than one season were included once using the season with the most recent bowling technique assessment and physical fitness assessment.

Bowlers were classified as 'injured' or 'not injured' based on whether they had a LBSI diagnosed that season. A LBSI was diagnosed if an MRI identified a stress reaction (bone oedema with no cortical breach) or stress fracture (bone oedema with cortical breach) (Kountouris et al., 2019) and the player was subsequently classified by medical staff as unavailable to train or play.

2.2. Procedures

2.2.1. Musculoskeletal screening and physical fitness assessment

The screening process consisted of a series of standardised tests undertaken in each of the six State Cricket Associations in Australia between June and October prior to the start of the respective season. The tests included height, weight, ankle dorsiflexion range of motion, hip internal and external range of motion, lumbo-pelvic stability test and the Biering Sorenson test which have all been previously described (Bayne et al., 2016). Other tests included the Star Excursion Balance Test (SEBT) (Hertel, Braham, Hale, & Olmsted-Kramer, 2006; Plisky, Rauh, Kaminski, & Underwood, 2006), lateral trunk flexion range of motion test (Nealon & Cook, 2018) and hip abduction and extension strength measures (Thorborg, Petersen, Magnusson, & Hölmich, 2010). When a test involved assessing both limbs it was delineated as front foot (FF-the foot contralateral to the bowling arm) or back foot (BF-the foot ipsilateral to the bowling arm). Physical fitness was assessed with a running two-kilometre time trial (2km TT) performed on flat ground.

2.2.2. Bowling volume

The number of balls bowled per day in training and matches was recorded daily by the bowler with staff oversight in a specialised database with mobile application interface. Bowling intensity was not measured. Bowling loads (volume and frequency) were calculated as averages over one, four, and 12-week windows during the period 1 October to 31 December. If a bowler sustained a LBSI before the end of December their average bowling loads (using the one, four, and 12-week windows) were calculated up to the date of injury. If a LBSI was sustained after December, the bowling loads were calculated as of December 31. This was done due to confidence that the data recorded during the period of October to December was accurate due to close monitoring of compliance by staff as players prepared for the respective Cricket Australia age group national championships and later season LBSI are likely to be related to prolonged overuse during the season (Alway, Brooke-Wavell, et al., 2019). Fifty-two-week bowling load was calculated up to the day of injury or end of season (31 March) in the uninjured group.

2.2.3. Technique assessment

Two-dimensional (2-D) bowling technique assessment was performed by national staff at each of the State Cricket Associations between February and October each year (i.e., at the end of one season or the beginning of the next). Assessment involved the bowler bowling 18 deliveries in a netted environment, each delivery aimed at a specific area on the wicket. Tests were recorded with high speed cameras (Basler Aca2000 – 165uc) operating at 150 frames per second. Vision was captured from a tripod 1.5m high, directly in line and 25m behind middle stump at the bowlers end of the pitch. The ball speed was also captured with a radar (Stalker Pro II radar, 34.7 GHZ) mounted in the same position as the high speed camera on a stand 1.6m high. The maximum ball speed achieved in the session was used in the subsequent analysis. Six balls to three specific regions of the pitch were then selected for analysis by an experienced sports scientist. The vision was analysed and placed in ranges of shoulder counter-rotation and trunk lateral flexion representing low (0-25 deg), moderate (25-40 deg) and high (> 40 deg) categories. These measures have previously been described as part of bowling biomechanical assessment and have been linked to injury in three-dimensional analyses.(Bayne et al., 2016; Portus et al., 2004) In a small number of cases (n = 7) where 3D analysis was available it was used. The method of data capture has been previously described (Portus et al., 2004) and the same testing procedure was followed as per the 2D testing except that it was indoor. The shoulder counter-rotation and lateral flexion variables were then categorised with respect to the three groups described above. The majority of the bowling screening (n = 101/150) was done in the same season (between July and March) or the previous season (31/150) as the bowling loads and musculoskeletal screening but in some cases it was not possible. In this situation if a screening was available within 2 years of the relevant season it was used in the analysis.

2.3. Statistical procedures

Univariate analyses were performed using simple logistic regression to identify variables from each of the measured factors (age, musculoskeletal screening and physical fitness, bowling volume, technique) which were significantly different between the injured and non-injured groups ($p < 0.05$). The initial analysis was then used as part of the decision making to identify variables to include in multivariate analysis. A hierarchical approach was also used to include variables that were not significantly different but based on previous research were thought to be relevant. Data used in the multivariate analysis were checked for multi-collinearity. The analysis involved a binary logistic regression (method: enter) with injury as the dependent variable and non-injured bowlers acting as the control. Contributing variables included in the model included: age at start of the season, height, star excursion balance test, average number of days bowled per week, 2km TT time, maximum ball speed, and shoulder counter-rotation. To simplify analysis, shoulder counter-rotation and trunk lateral flexion were dichotomised into two groups (< 40 degrees and > 40 degrees) as values > 40 degrees have been associated with LBSI (Bayne et al., 2016; Portus et al., 2004). Lumbo-pelvic control was dichotomised into level 0-1 and level 2-5 as previous research has shown very low values on the scale are related to LBSI (Bayne et al., 2016). Analysis was completed using SPSS (version 25, IBM, Armonk, NY, USA). The process from identification to analysis is outlined in Figure 1.

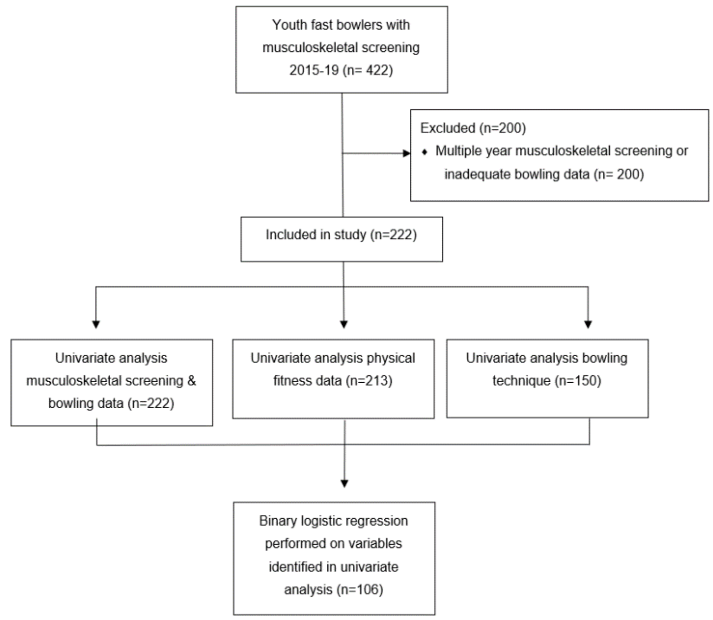

Figure 1: Flow diagram showing process from identification of subjects to analysis of data

3. Results

In total 49 of the 222 bowlers sustained a LBSI. Univariate analyses identified injured bowlers were younger ($p = 0.005$) and taller ($p = 0.007$) than their non-injured counterparts. Injured bowlers also performed less efficiently on the SEBT (FF $p = 0.006$, BF $p = 0.005$), and on average bowled more days per one week ($p = 0.009$), 4 weeks ($p = 0.042$) and 12 weeks ($p = 0.008$) than the non-injured group (Table 1). There was no difference between the two groups in bowling technique analysis (Table 2).

For the multivariate analysis, age, height and SEBT BF (only one SEBT was used as the FF and BF measures were highly correlated) were used based on the significant differences in the simple logistic regression analysis. The workload measures were all highly correlated (Pearsons r > 0.9) and therefore only the one-week average days per week measure was chosen as it had a similar effect size and more data in the LBSI group than the 12-week average days measure (some of the LBSIs occurred with less than 12 weeks of bowling load). In addition to these variables, the 2 km TT (poor aerobic fitness has been linked to lower limb injury in the military) (Tomes, Sawyer, Orr, & Schram, 2020), maximum ball speed (higher speeds are associated with greater lumbar forces (Crewe et al., 2013) and shoulder counter-rotation (high shoulder counter-rotation has been linked to LBSI) (Portus et al., 2004) were also included. The Nagelkerke R^2 value for the analysis was 0.36 and the results of the regression analysis are detailed in Table 3.

Table 1: Univariate analyses of continuous variables

	Injured	n	Not Injured	n	*p*	Effect size
Age (years)*	17.0 (1.0)	49	17.5 (1.1)	173	0.005	0.48
Height (cm)*	188.9 (5.8)	48	186.1 (6.2)	169	0.007	0.47
Weight (kg)	81.7 (8.8)	47	80.2 (7.9)	168	0.240	
Star Excursion Balance Test FF (cm)*	99.1 (6.9)	35	103.6 (8.2)	103	0.006	0.59
Star Excursion Balance Test BF (cm)*	98.8 (6.7)	35	103.6 (8.5)	103	0.005	0.63
Ankle dorsiflexion lunge FF (cm)	11.6 (3.3)	39	11.4 (3.2)	120	0.755	
Ankle dorsiflexion lunge BF (cm)	12.0 (3.0)	39	11.8 (3.4)	120	0.704	
Lateral trunk flexion FF (% leg length)	0.74 (0.03)	38	0.75 (0.05)	116	0.138	
Lateral trunk flexion BF (% leg length)	0.74 (0.02)	38	0.75 (0.05)	116	0.099	
Hip internal rotation FF (deg)	36 (8.6)	20	38 (13.0)	72	0.578	
Hip internal rotation BF (deg)	35 (10.7)	20	38 (11.2)	72	0.303	
Hip external rotation FF (deg)	52 (10.7)	20	50 (13.1)	72	0.631	
Hip external rotation BF (deg)	52 (8.8)	20	49 (13.3)	72	0.405	
Prone extension hold (sec)	130 (31)	27	129 (39)	124	0.844	
Hip abduction FF (% body weight)	0.25 (0.04)	43	0.26 (0.06)	154	0.342	
Hip abduction BF (% body weight)	0.25 (0.04)	43	0.26 (0.06)	153	0.623	
Hip extension FF (% body weight)	0.39 (0.08)	41	0.41 (0.1)	148	0.324	
Hip extension BF (% body weight)	0.40 (0.09)	41	0.43 (0.1)	149	0.173	
2 km time trial (mins)	7 min 41 secs (38 secs)	46	7 min 48 secs (38 secs)	167	0.260	
Total # of balls 52 weeks	2749 (1171)	49	2557 (1151)	172	0.310	
Total bowling days 52 weeks	77.5 (31)	49	69.6 (29)	172	0.100	
Average # of balls 1 week	85 (24)	49	76 (38)	170	0.120	
Average # of balls 4 weeks	350 (102)	49	324 (167)	170	0.290	
Average # of balls 12 weeks	1057 (293)	45	922 (458)	170	0.650	
Average days bowling 1 week*	2.3 (0.6)	49	2.0 (0.9)	170	0.009	0.48
Average days bowling 4 weeks*	9.5 (2.4)	49	8.2 (4)	170	0.042	0.39
Average days bowling 12 weeks*	28.3 (7.4)	45	23.6 (11.1)	170	0.008	0.50
Max Ball Speed (km/h)	123.1 (5.7)	35	121.6 (6)	115	0.190	

Note: * $p < 0.05$

Table 2: Cross tabulation tables and univariate regression analysis of categorical variables.

		Injured	Not injured	*p*
Lumbo-pelvic control	Level 0 or 1	4	28	0.171
	Level 2-5	42	136	
Shoulder counter-rotation	≤ 40 deg	15	65	0.281
	> 40 deg	19	54	
Lateral trunk flexion (max)	≤ 40 deg	19	50	0.154
	> 40 deg	15	69	

Table 3: Multivariate analyses of possible risk factors of lumbar bone stress injury in youth cricket fast bowlers (n = 106).

	Exp (B)	*p*
Age (years)*	0.334 (0.184-0.605)	0.000
Height (cm)*	1.122 (1.027-1.226)	0.011
Star Excursion Balance Test BF (cm)	0.944 (0.883-1.01)	0.097
Average days bowling 1 week	2.032 (0.874-4.726)	0.100
2 km time trial (min)	0.448 (0.179-1.121)	0.086
Max ball speed (km/h)*	1.115 (1.016-1.225)	0.022
Shoulder counter-rotation (deg)	1.142 (0.394-3.309)	0.807
Constant	0.001	0.534

Data presented as Exp (B) (lower and upper 95% confidence intervals). BF = back foot. * $p < 0.05$

Three variables were identified as risk factors with the risk of LBSI being 2.99 (1/0.334) times higher for every year younger in our cohort aged between 15 and 20 years. Bowlers were 1.1 times more likely to be injured for every centimetre taller and 1.1 times more likely for every kilometre per hour faster the ball was bowled.

4. Discussion

The risk of LBSI in youth fast bowlers is multi-factorial. This study is the first that has utilised multivariate analysis to quantify the relative influence of a range of routinely measured individual factors, including risk factors identified in previous research. This approach has enabled the authors to identify that the combination of younger age, a greater height and a faster bowling speed increases the risk of LBSI. Interestingly, bowling workload and technique were not significant factors in our model. The model explained approximately 36% of the variance suggesting that there are other risk factors which contribute to the development of LBSI in youth fast bowlers. This has important implications on where to best target future research and injury prevention programs.

Younger bowlers were approximately three times more likely to sustain a LBSI for each year younger within the age range 15-20 years. This finding is broadly consistent with previous research showing that bowlers under the age of 22 are particularly at risk of bone stress injury (Alway, Brooke-Wavell, et al., 2019; Blanch et al., 2015). However, other studies specifically investigating youth bowling populations have not demonstrated an age effect (Bayne et al., 2016; Kountouris et al., 2019). The current study differed from those previous with larger subject numbers and a slightly older cohort.

Taller bowlers were 1.1 times more likely to sustain a LBSI for every centimetre taller. Previous research has not found a height difference in junior bowlers with lower back injuries (not specifically LBSI) (Bayne et al., 2016; Elliott et al., 1992; Elliott, Davis, Khangure, Hardcastle, & Foster, 1993). Junior bowlers with low back injury have a higher ball release height (Foster et al., 1989), but this is influenced by other factors such as trunk lateral flexion and knee extension so it is hard to draw any conclusions with respect to height. It is possible that taller bowlers may generate greater forces in the lumbar spine due to longer lever arms which would amplify the risk of LBSI.

The increased risk with younger age and taller height may be partly attributed to a transient period of reduced bone mineral density during high linear growth (Bailey, Wedge, McCulloch, Martin, & Bernhardson, 1989; Christoffersen et al., 2016). Recent evidence has identified a bigger reduction in bone mineral density in taller males during periods of rapid growth, leaving them potentially more susceptible to fracture (Yu et al., 2019). In fact, peak lumbar spine bone mineral density is not attained until 23 years of age in males (Xue et al., 2020), with up to 10% of bone mineral content (BMC) added after linear growth has ceased (McCormack et al., 2017). It is therefore likely that the combination of being taller and younger leaves an individual at risk of a larger transient reduction in bone mineral density. Furthermore, bone architectural changes during adolescence cause a transient phase of high cortical porosity (Cheuk et al., 2018), which may leave the bone more susceptible to fracture. This may be particularly relevant to LBSI as the strength of the pars interarticularis cortical bone is considered a key factor in the ability to resist tensile and shearing forces (Cyron & Hutton, 1979).

Fast bowlers have been shown to have site-specific patterns of increased bone mass in the lumbar spine (Alway, Peirce, King, Jardine, & Brooke-Wavell, 2019), which likely gradually develops as a bowler matures. Further, during adolescence an increase in muscle strength precedes an increase in BMC by 3-6 months, consistent with the hypothesis that increased muscular load is an important driver of bone adaptation (Rauch, Bailey, Baxter-Jones, Mirwald, & Faulkner, 2004; Takei, Taketomi, Tanaka, & Torii, 2020). Collectively, the evidence suggests that younger bowlers are at increased risk of LBSI as they grow taller and become stronger, with a transient period where BMC and bone architecture adaptations lag behind increases in muscle and body weight forces. This risk decreases with age as bone matures and adapts to the forces of the fast bowling action.

Faster bowling speed was also a risk factor for the development of LBSI. This finding is intuitive given higher bowling speeds are associated with higher lumbar shear forces and more rapid development of ground reaction force (Crewe et al., 2013). Yet previous research has not reported this link (Bayne et al., 2016; Foster et al., 1989; Portus et al., 2004). This may be due to differing subject numbers, age ranges, and bowling ability between the cohorts. The current study had lower average speeds (~121 km/h) compared with the only other study to report ball speeds in junior bowlers (129 km/h) (Bayne et al., 2016) and included a wider range of bowling ability as drawn from a nation-wide testing of youth bowlers rather than a more select elite group.

Our experience with the development of youth bowlers over many years suggests that faster bowlers tend to self-select towards playing at a higher competition level given bowling faster is seen as a competitive advantage. Higher competition levels typically involve greater bowling loads. Although bowling volume was not identified as a risk factor in the current study, previous research has shown high weekly volumes to be a risk factor in the development of injury (Dennis et al., 2003) and lumbar stress fracture (Alway, Brooke-Wavell, et al., 2019) in senior bowlers. This combination of younger bowlers bowling faster, with greater bowling loads and experiencing rapid increases in strength (Rauch et al., 2004), creates a higher-risk scenario, requiring careful preparation and management to avoid LBSI as they do not have the bony maturity in their posterior-vertebral lumbar spine arches to cope with this load.

A more frequent bowling workload has been linked to injury (Dennis, Finch, & Farhart, 2005) and LBSI (Kountouris et al., 2019) in youth fast bowlers. In the current study, univariate analysis identified more frequent bowling in one, four- and 12-week intervals in the LBSI group, consistent with the previous studies. However, this was not a significant risk factor in the multivariate model. One explanation for this is the inability to pinpoint an injury date as LBSI typically develops over time (Alway, Brooke-Wavell, et al., 2019; Kountouris et al., 2019) and is only confirmed when symptoms (which in younger age groups may be poorly defined or localised (Tsukagoshi et al., 2020) or other clinical factors dictate imaging. Bowling workload may therefore have been modified in the weeks preceding diagnosis. Bone marrow oedema has also been shown to be present in approximately 40% of junior bowlers at the start of the pre-season (Kountouris et al., 2019), suggesting a lower threshold for developing clinically diagnosed LBSI which may skew bowling workload data.

Univariate analysis also identified a poorer performance of the SEBT in the LBSI group. This was consistent with previous cricket research which had shown a link between low scores on the SEBT and lower quarter injury in a group of fast bowlers (Olivier, Stewart, Olorunjub, & McKinon, 2015). The test challenges balance, strength, and mobility, making it a good composite screening tool. However, it was not a significant risk factor in the multivariate analysis suggesting other factors were more important in the development of LBSI. None of the other musculoskeletal screening measures reached statistical significance. Previous research has provided some evidence supporting the use of the prone extension test and lumbo-pelvic control test (Bayne et al., 2016) suggesting at an individual level musculoskeletal screening may still add value by identifying physical deficits and directing training programs. Physical fitness, as measured by the 2 km TT was not associated with an increased risk of LBSI. However evidence from military populations has linked poorer aerobic fitness to an increased risk of lower limb stress fractures (Rauh, Macera, Trone, Shaffer, & Brodine, 2006; Valimaki et al., 2005) and it is recommended that young fast bowlers are more likely to benefit than be hindered by higher levels of aerobic fitness.

It was also noteworthy that there was no connection identified between LBSI and bowling technique measures in the current study. Previous studies have identified greater shoulder counter-rotation (Foster et al., 1989; Portus et al., 2004) and lumbar lateral flexion (Bayne et al., 2016) as risk factors for lumbar stress fracture. The previous studies all used three-dimensional laboratory-based testing whereas the current study used a predominantly two-dimensional field-based approach. There is therefore a possibility that the reduced accuracy of the testing procedure may in part account for this discrepancy, although internal validation of the two- and three-dimensional testing methods suggest that the results are valid and inter-changeable (unpublished data). Scrutiny of the testing results showed approximately 45% (see table 2) of the non-injured bowlers had excessive shoulder counter-rotation (> 40 degrees) meaning it is very common in a junior bowling cohort and may not be a risk factor in its own right, unless combined with the other risk factors identified.

The multivariate model accounted for approximately 36% of the variance in LBSI risk, suggesting that a large proportion of the injury risk cannot be explained by age, height and bowling speed. Although age and height were identified as risk factors, rate of growth was not specifically considered. Rate of growth has been linked to an increased injury risk in junior soccer (Kemper et al., 2015) and junior athletics (Wik et al., 2020) where rapid linear growth rate and rapid skeletal maturity (assessed by X-Ray) were both risk factors for bone injury. Another possible genetically determined risk factor is intrinsic bone structure, with evidence showing a thinner pars interarticularis with less cortical bone may be more at risk of injury (Cyron & Hutton, 1979). This is consistent with more recent work showing elite military personnel with reduced tibial stiffness were 7 times more likely to suffer a stress fracture (Jepsen et al., 2013) and male runners with a stress fracture history having narrower tibias at the mid diaphysis (Popp, Frye, Stovitz, & Hughes, 2020). Future research should therefore consider incorporating measures of growth and bony architecture. Other possible risk factors include the influence of nutrition on bone health such as low energy availability, vitamin D deficiency, and calcium loss (Sale & Elliott-Sale, 2019) A further consideration for future research is to quantify all physical activity rather than just bowling volume. Together, these additional factors may contribute to the variance in LBSI risk which may help practitioners understand how a bowler exposed to similar loading as his peers may be injured when others are not.

The findings of this study should be considered in light of the following limitations. Data were collected from six different state locations in Australia over five seasons, which may have introduced variability in measurement. This was mitigated by standardised procedures and staff training. Bowling technique assessment was performed by the same national staff using the same equipment, however this assessment was not always available for the season of injury. Bowling technique appears relatively stable across spells of 10 overs (Schaefer, O'Dwyer, Ferdinands, & Edwards, 2018) and across a season (Schaefer, O'Dwyer, Ferdinands, & Edwards, 2017) but technique may change over two years with coaching intervention (Ranson, King, Burnett, Worthington, & Shine, 2009). Bowling volume was reported by bowlers and staff without objective measurement (e.g., wearable technology, video) as this was not feasible in this cohort. Additionally, bowling intensity was not recorded. Physical load from other cricket (e.g., throwing, batting) and non-cricket activities were not accounted for. Nevertheless, this study utilised routinely measured factors, and therefore provides guidance to practitioners on how to take such factors into consideration when managing young fast bowlers.

The risk of LBSI in youth fast bowlers is multi-factorial. Younger age, increased height and faster bowling speed were identified as risk factors which accounted for approximately 36% of variance between bowlers who sustained a LBSI and bowlers who did not. Practitioners should be mindful that immature vertebrae may be more susceptible to bone stress injury, and therefore assist bowlers to manage their bowling and non-bowling loads to promote positive adaptation for longevity in the sport. The relatively weak predictive model suggests that individual factors beyond the risk factors identified in this study should be considered when managing fast bowlers through adolescence.

Conflict of Interest

The authors declare no conflict of interest.

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