MRI bone marrow oedema precedes lumbar bone stress injury diagnosis in junior elite cricket fast bowlers

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► Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/bjsports-2017-097930).

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Accepted 30 October 2018
Published Online First 13 November 2018

Check for updates

To cite: Kountouris A, Sims K, Beakley D, *et al. Br J Sports Med* 2019;**53**:1236–1239.

ABSTRACT

Objectives Lumbar bone stress injury ('bone stress injury') is common in junior fast bowlers. The repetitive loading of cricket fast bowling may cause bone marrow oedema (BMO), detectable on MRI, before the bowler suffers from symptomatic bone stress injury. We investigated the temporal relationship between BMO, bone stress injury, along with bowling workload correlates, in elite junior fast bowlers throughout a cricket season.

Methods 65 junior fast bowlers were prospectively monitored for one 8-month cricket season. For research purposes, participants had up to six MRI scans at set times in the season; findings were withheld from them and their clinicians. Standard practices for bowling workload monitoring and injury diagnosis were followed.

Results 15 (23%) participants developed bone stress injury during the study. All 15 of these participants had BMO detected on at least one of the preceding MRI scans, including the scan immediately prior to diagnosis. The risk of BMO progressing to bone stress injury during the season was greatest for participants with BMO present 2 weeks prior to the national championship tournament (period of high load) (RR=18.9, OR=44.8). Both bone stress injury and BMO were associated with bowling a higher percentage of days in training and having a shorter bowling break during the season. The number of balls bowled and acute-to-chronic workload were not associated with imaging abnormalities or injury.

Conclusion The presence of BMO on MRI in asymptomatic junior cricket fast bowlers confers a very high risk for bone stress injury. The risk may be managed by MRI screening and monitoring bowling frequency.

INTRODUCTION

Lumbar spine bone stress injury (bone stress injury (BSI)) affects the posterior vertebral arch in as many as 67% of cricket fast bowlers in any given season.[1 2] During adolescence, the vertebrae have low bone mass,[3] and the ossification of the neural arch may be incomplete until the mid-20s.[4 5] Elasticity of the intervertebral discs during adolescence allows increased stress on the neural arch.[4] Given the predisposition of junior fast bowlers to BSI, the long recovery times[6] and the risk of similar injury later in their career,[7 8] it is important to understand and manage the risk in this population.

Bone stress is purported to progress along a continuum, beginning with early radiological evidence of bone stress in the absence of symptoms, with symptoms and radiological evidence of a fracture line emerging later.[9] MRI can detect bone marrow oedema (BMO)—an early stage of bone stress.[10–13] In both adult and junior fast bowlers, MRI-detected BMO at the start of the season has been strongly linked to the development of BSI later in the season.[14–16]

Cricket bowling workload is a modifiable risk factor associated with a BSI.[7 17 18] High volume and/or inadequate recovery,[19–22] workload spikes[23] and low workload[22] have all been associated with injury in adult fast bowlers. In junior fast bowlers, bowling >50 balls per day (volume) or bowling on 2.5 days per week (frequency) in both training and matches doubled the risk of injury.[2] Fewer than 3.5 days between bowling sessions were associated with a threefold risk of injury.[2] Note that the majority of cricket-related workload studies include all types of injuries sustained by fast bowlers.

The only study to consider injury by tissue type reported that all bone stress injuries (lower limb and spine) were associated with a high bowling workload in the medium term (≥900 balls in 3 months) coupled with low career bowling workload. Strikingly, acute bowling workload (the number of balls bowled in a match) was not associated with injury.[24] Therefore, to better understand bowling workload as a risk factor of a BSI in junior fast bowlers, research must be specific to both injury and population.

In this cohort study, we used regular and preplanned MRI scans to monitor the lumbar spine of junior elite fast bowlers. We sought to test the association between clinically detected BMO and BSI. A secondary aim of the study was to identify bowling workload factors that may be associated with BMO and subsequent BSI.

METHODS

Participants were 65 Australian junior elite fast bowlers selected in an under 17 or under 19 state or territory squad. All participants were free of injury at the start of the study (beginning of preseason training—July to August) and agreed to have serial lumbar spine MRI at designated clinics in their state or territory over the course of one cricket season (maximum of 6 scans in 8 months). The study was approved by a University Human Research Ethics Committee, and each participant provided informed consent, including parental consent for participants under 18.

Standard player management strategies: injury and bowling workload

The Cricket Australia online Athlete Management System (AMS, Fairplay) was used to collect medical and bowling workload information throughout the season, as per standard practice. Medical staff (physiotherapist and/or doctor) for each state and territory squad entered injury details and their consultation notes in the AMS. They made the diagnosis of a BSI using their clinical judgement and imaging modalities (external to the study). In those cases, the participant was unable to bowl for a period in the season ('time loss' definition of injury). The state and territory medical teams were not part of the research team and were blind to the results of the MRI conducted as part of this study. Participants entered the number of balls bowled in training and matches on the AMS. This included balls bowled with their respective state or territory squad, and also their club or school team.

Imaging methods

Lumbar spine MRI was performed at one of the seven state and territory radiology clinics. The imaging protocol was developed by consensus of the study radiologists who used both 1.5 and 3.0 Tesla MR scanners (online supplementary table 1).

MRI was performed:

- **Research scan 1 (baseline):** before preseason training (July to August 2014).
- **Research scan 2:** 10 weeks prior to the National Championships for the age group (September or November 2014 depending on date of age group championships).
- **Research scan 3:** 6 weeks prior to the National Championships (October or December 2014).
- **Research scan 4:** 2 weeks prior to the National Championships (November 2014 or January 2015).
- **Research scan 5:** immediately after the National Championships (December 2014 or January to February 2015).
- **Research scan 6:** 4 weeks after the National Championships. (February or March 2015).

Any participant who was diagnosed with a BSI had no further research MRI scans. During the study period, all diagnosed BSI ended the season for that player (clinical decision).

Radiologists assessed the left and right posterior vertebral arch at each vertebral level (L1-L5) for high signal (BMO) on the sagittal and coronal T2 fat suppressed or short-tau inversion recovery sequences, recording BMO as either present or absent. Radiologists were blind to participants' injury status and did not have any role in the injury management of participants during the study.

Analysis

Injury data (presence or absence of BSI) and MRI BMO data (presence or absence of BMO at any vertebral level or on either side) were collated. Relative risk (RR) and the odds ratio (OR) of developing a symptomatic BSI in participants who had BMO on any of the MRI scans during the study were calculated. In the instance of a zero cell count, 0.5 was added to each cell to compute RR and OR.[25] Positive predictive value (PPV) and negative predictive value (NPV) of BMO were also calculated.

Bowling workload data were categorised as preseason (balls bowled in training prior to the first match of the cricket season) or in-season (balls bowled in training and matches after the commencement of the first match of the season). Observations recorded after a BSI diagnosis were not included. Bowling workload was calculated in rolling intervals of 4, 8 and 12 weeks. These intervals are consistent with previously identified BSI lag times.[20 26] The acute:chronic workload ratio was calculated as the rolling average number of balls bowled in the previous 7 days, compared with the average number of balls bowled per week in the previous 28 days. Maximum days between sessions were calculated to reflect any prolonged recovery period during the season.

Analyses were performed using SPSS, V.24.0. Statistical significance was set at $p<0.05$. Descriptive statistics (mean, SD, independent samples t-test) were calculated for preseason, in-season and for the full season (pre-season and in-season combined), comparing bowling workloads between participants who did and did not sustain a BSI, and participants who did and did not have BMO detected during the season. To ascertain the certainty of a meaningful difference between groups, 95% confidence limits (CLs) were calculated and probabilistic inferences made according to the scale: 25%–75%, possible; 75%–95%, likely; 95%–99.5%, very likely; >99.5%, most likely.[27]

Generalised estimating equations (GEE) were used to evaluate the association between bowling workload and BSI, and bowling workload and BMO. A binary logistic model with an exchangeable correlation structure was used. Models assessed the predictive ability of bowling workload in the 4, 8 and 12 weeks prior to BSI diagnosis and BMO detection.

RESULTS

The mean age of participants at the start of the study was 17.3 years (range 14.7–18.8 years). Fifteen (23%) participants were diagnosed with BSI during the season; 14 were clinically diagnosed with stress fractures (fracture line visible on imaging), and 1 with a stress reaction (MRI BMO only). The vertebral levels affected were L4 (n=6), L5 (n=4), L3 (n=4) and L2 (n=3) (two participants had BSI diagnosed at multiple levels—one participant at two levels and the other at three levels). There was no difference in the age of participants who developed a symptomatic BSI during the study (17.2 years, range 14.8–18.8 years) and those who did not (17.4 years, 14.7–18.8 years).

MRI detected BMO preceded BSI diagnosis

Thirty-eight (58%) participants had BMO detected on one or more scans during the season. Of these participants, 15 (39%) went on to suffer a clinical BSI during the season, 14 (37%) still had a persistent BMO but no symptoms at the end of the season and in 9 (24%) cases the BMO resolved during the season. Participants who had BMO detected at scan 4, 2 weeks prior to the National Championships which was a period of high load, were most at risk of BSI (RR=18.9 (95% CI 2.7 to 134.3), OR=44.8 (5.1–390.3)) (table 1).

All 15 participants who sustained a BSI during the season had BMO detected at the corresponding site (level and side) of the vertebra in the scan immediately prior to diagnosis. The first detected instance of BMO was the baseline scan 1 (n=10), scan 2 (n=3), scan 3 (n=0), scan 4 (n=1), scan 5 (n=1) and scan 6 (n=0).

The number of days between the first appearance of BMO on a research scan and the player reporting pain (recorded in the AMS – medical record) of what proved to be BSI, was a mean of 96 days (SD 70) and median 112 days (range 5–224). Eight participants (of the 15) with clinical BSI had additional BMO at other levels and/or bilaterally that did not progress to symptomatic BSI (eg, no pain on the side of the BMO).

Bowling frequency a risk factor for BSI

Bowling frequency throughout the season

The percentage of days bowled in training was very-to-most likely higher throughout the season for participants who sustained a BSI compared with those who did not (preseason 39%±23 vs

Table 1 Contingency table outlining number of participants with and without BMO detected at each MRI scan and BSI outcome for the season

	BMO	BMO	No BMO	No BMO				
Scan	BSI	No BSI	BSI	No BSI	RR (95% CI)	OR (95% CI)	PPV (95% CI)	NPV (95% CI)
1	10	9	5	41	4.8 (1.9 to 12.3)	9.1 (2.5 to 33.2)	52.6 (35.8 to 68.9)	89.1 (79.9 to 94.4)
2	11	15	2	35	7.8 (1.9 to 32.4)	12.8 (2.5 to 65.1)	42.3 (31.2 to 54.3)	94.6 (82.8 to 98.5)
3	10	16	3	32	4.5 (1.4 to 14.7)	6.7 (1.6 to 27.7)	38.5 (27.5 to 50.7)	91.4 (79.5 to 96.7)
4	13	9	1	31	18.9 (2.7 to 134.3)	44.8 (5.1 to 390.3)	59.1 (44.4 to 72.3)	96.9 (82.3 to 99.5)
5	13	11	1	30	16.8 (2.4 to 119.6)	35.5 (4.1 to 303.8)	54.2 (41.1 to 66.7)	96.8 (81.8 to 99.5)
6	10	10	2	29	7.8 (1.9 to 31.8)	14.5 (2.7 to 77.8)	50.0 (35.6 to 64.4)	93.6 (80.2 to 98.1)
Any	15	23	0	27	22.3 (1.4 to 356.6)	36.3 (2.1 to 639.5)	39.5 (32.6 to 46.8)	100.0

RR, OR, PPV and (NPV are presented with 95% CIs.
BMO, bone marrow oedema; BSI, bone stress injury; NPV, negative predictive value; PPV, positive predictive value; RR, relative risk.

26%±10, p=0.002; in-season 41%±20 vs 29%±9, p=0.002; full-season 26%±6 vs 21%±5, p=0.001). A similar pattern was noted for participants who had BMO during the study, who very likely bowled a higher percentage of days at training during the pre-season (32%±17 vs 23%±8, p=0.013) and over the full season (23%±6 vs 19%±6, p=0.010), compared with participants with no BMO. No differences were noted for either BSI or BMO for percentage of days bowled at matches.

Maximum days between sessions, indicative of a recovery period during the season, were most likely shorter for participants who sustained a BSI compared with those who did not (10 days±6 vs 19 days±8, p<0.001). However, in the 12 weeks prior to BSI, maximum days between sessions was not a predictor. Participants who had BMO during the study had a possibly trivial shorter recovery period during the season (16 days±8 vs 19 days±9 for no BMO, p=0.121), yet maximum days between sessions were a strong negative predictor of BMO detected in the next 4–12 weeks (OR 0.98 (95% CL 0.96 to 1.00), p≤0.010).

Average weekly bowling frequency

Days bowled per week were likely trivially higher on average for participants who sustained a BSI (2.1 days±0.4 vs 1.8 days±0.4 for no injury, p=0.051), and most likely trivially higher for participants who had BMO during the study (2.0 days±0.4 vs 1.8 days±0.4 for no BMO, p=0.015). Days bowled per week in the preceding 12 and 8 weeks were a positive predictor of BSI (OR 2.8 (1.2–6.5), p=0.021; 2.4 (1.3–4.2), p=0.004, respectively), and days bowled per week in the preceding 4 weeks were a positive predictor of BMO (OR 1.2 (1.0–1.5), p=0.036).

Days between bowling sessions were likely lower on average for participants who sustained a BSI (1.7 days±0.5 vs 2.4 days±0.8 for no injury, p=0.004), and likely lower for participants who had BMO during the study (2.0 days±0.6 vs 2.6 days±0.9 for no BMO, p=0.007). Days between sessions in the preceding 12 and 8 weeks were a strong negative predictor of BSI (OR 0.4 (0.2–0.8), p=0.005; 0.5 (0.3–0.8), p=0.009, respectively). Days between sessions were not a predictor of BMO in the next 12 weeks.

Balls per session, balls per week and ACWR were not different between participants with or without BSI or with or without BMO, nor were these workload factors predictive of injury or BMO in the next 12 weeks. Complete season workload statistics are detailed in the online supplementary tables 2–5.

DISCUSSION

Our paper has important implications for clinicians, coaches and support staff of junior elite fast bowlers.

The case for MRI

We report the consistent presence of BMO on MRI in the weeks-to-months preceding BSI diagnosis. This finding extends previous research,[14–16] with more detail of how MRI scans may be a useful tool for early detection of potentially career-limiting BSI. Whether intervention (eg, rest from bowling) will automatically prevent BSI from developing is outside the scope of this study but our clinical impression is that such an intervention (stopping bowling) would likely prevent any cases developing to become a frank BSI.

Two-thirds (67%) of the participants who developed BSI during the study had BMO on baseline MRI. This may be attributable to unresolved BMO from the previous cricket season, and/or off-season activities (eg, self-directed cricket training, other sports). Although the link between BMO and the development of BSI was evident in this study, there were a number of false positive MRI results (25 participants developed BMO but no BSI). However, the long lag time between BMO and the development of symptoms could mean that even those who did not develop symptoms during the study could be more vulnerable for BSI in the off-season or the start of the next season.

Our data suggest that MRI be used to screen junior elite fast bowlers at the start of each cricket season to inform player management. Approximately 40% of participants had BMO detected at the start of the season, and approximately 70% of participants had BMO detected at any given point during the season or at the end of the season. With such a large proportion of fast bowlers being flagged, clinical judgement is critical for appropriate management of bowlers at both the individual and team levels.

Our management of elite fast bowlers with asymptomatic BMO involves a period of de-loading to allow tissue to return to normal imaging. No one knows how quickly BMO reverses; we know it takes 12–16 weeks for the MRIs of athletes with BSI[28] to appear normal. We contend that detecting BMO before a player has bone stress-related back pain could prevent the 6–12 months out of bowling associated with stress fracture.[29] Based on this and our clinical experience, we hypothesise that it could take 4–12 weeks for BMO to resolve in asymptomatic athletes, depending on the severity of BMO. We recommend follow-up MRI to evaluate if BMO has resolved before allowing return to bowling, but we do not have data to support this clinical decision.

The case for workload monitoring

Bowling workload—specifically bowling frequency—was associated with BMO and BSI. Workload monitoring should include days bowled. The association between more frequent bowling (loading) sessions and BSI is consistent with bone physiology/

pathophysiology, whereby there is a balance between mechanical stimulation that results in micro-damage and sufficient time for bone remodelling.[30] Our finding that continuous loading is a risk for junior fast bowlers extends previous research that associated the combination of high medium-term loading and low career workload with stress fractures in fast bowlers.[24]

A key time where BMO developed in the current study was the transition from preseason to in-season. The addition of matches in in-season increased the percentage of days bowled and reduced the average number of days between sessions to <2. The modelling used in our analysis suggest that one less day between bowling sessions could double the risk of BSI. The injury threshold of approximately 2 days between sessions in this study is <3.5 days identified by Dennis *et al*.[2] A possible explanation for this disparity is that Dennis *et al* applied 3.5 days as a cut-off for analysis and included all overuse-type injuries (rather than only bone stress injuries in the current study) either side of this cut-off. Our study supports Dennis *et al*'s recommendation that junior fast bowlers have 2–3 days between sessions. This should be reflected in junior bowling guidelines. Coaches should consider reducing the number of bowling training sessions from preseason to in-season to account for the addition of match load.

Another key time in the season for junior elite fast bowlers is national or international tournaments where bowlers may be expected to bowl in up to 10 matches in 2–3 weeks. Coaches may consider limiting bowling frequency (by resting a bowler out of one or more matches) or scheduling a period of complete rest from bowling in the lead-up to a tournament, to reduce the overall percentage of days bowled in the period surrounding a tournament.

In this study, participants who remained free of BMO during the season had at least one period of approximately 19 consecutive days between bowling sessions, compared with approximately 16 non-bowling days for participants with BMO and approximately 10 non-bowling days for participants with BSI. Modelling suggests that an additional 7 days of recovery during the season reduces the chance of BMO being detected by ~20%. Thus, a strategic recovery period ('planned bowling break') of 2–3 weeks during the season may allow early bone stress to resolve or stop it from progressing to symptomatic BSI. This may be programmed into the schedule or be achieved by embracing opportunities such as holidays or minor injury. Where feasible, the need and/or required duration of a strategic recovery period to resolve BMO may be supported by MRI.

The acute:chronic workload ratio for balls bowled (external load) was not associated with increased risk of BSI. This finding differs from that of a study that associated high bowling acute:chronic workload ratio with injury in adult fast bowlers.[23] This is also contrary to findings in others sports where high acute:chronic workload ratio has been associated with injury.[31–33] It is possible that the risk of a high bowling acute:chronic workload ratio may not be specific to BSI, as other studies included all bone and soft tissue injuries. This explanation is consistent with data reported by Orchard *et al*[24] who highlighted the need to consider load specific to tissue type. Our clinical advice is that coaches and support staff still monitor and manage acute:chronic workload ratio spikes to reduce the risk of other injuries in bowlers. For instance, a scheduled 2–3 week break in bowling should maintain other forms of training (and thus, the chronic load on tissue) such as fielding, batting, and strength and conditioning.

Limitations

Other factors may contribute to whether BMO progresses, resolves or is maintained. Bowling technique and intensity are two key factors which have been previously been associated with both BSI[34] and BMO.[35] Additionally, non-bowling workload and participation in other sports and activities were not accounted for. Other factors including stage of maturation, physical conditioning, nutritional status and genetic predisposition may also influence whether or not BMO progresses to BSI in fast bowlers.[2 18]

The multicentre approach enabled a large sample size which is a strength of the study, however also introduces potential error from different MR scanners and inherent variability in clinical judgement in what different radiologists consider 'abnormal' BMO. Similarly, medical teams used their standard assessment and imaging practices to diagnose BSI.

What are the new findings?

- MRI-detected bone marrow oedema (BMO) was present before clinical diagnosis in 100% of cases of lumbar bone stress injury (BSI).
- BMO was typically detected 3–4 months prior to symptomatic BSI.
- More frequent bowling in training and matches was associated with BMO and BSI. We recommend junior fast bowlers average 2–3 days between bowling sessions, and have a period of 2–3 weeks of no bowling during the season.
- MRI screening at the start of a cricket season, or around a period of high bowling frequency (such as a tournament), may help identify bowlers at higher risk of sustaining a BSI in the short term to medium term.
- Our study did not test MRI screening as a management tool; we provide some clinical suggestions based on both published literature and our experience with elite fast bowlers.

Acknowledgements The authors want to acknowledge the radiologists who were involved in the study: Dr J Fitzgerald (QScan, Brisbane), Dr E Koh (Envision Radiology, Perth), Dr S Zadow (Dr Jones & Partners, Adelaide), Dr R Jones (Regional Imaging, Hobart), Dr P Lucas (Stadium Imaging, Sydney) and Dr I Stewart (National Capital Imaging Group, Canberra); the state and territory physiotherapists and doctors who managed the participants through the season; and Ms T Mott, Cricket Australia's Sports Science & Sports Medicine Administrator for collating research data and administrative duties

Contributors All authors contributed to the publication substantially.

Funding Cricket Australia funded the study in its entirety.

Competing interests None declared.

Patient consent Obtained.

Ethics approval La Trobe University.

Provenance and peer review Not commissioned; externally peer reviewed.

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