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Radiological healing of lumbar spine stress fractures in elite cricket fast bowlers

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ABSTRACT

Objectives: Review magnetic resonance imaging (MRI) of elite adult fast bowlers with a history of lumbar spine stress fracture for evidence of bone healing. The findings will determine whether bone healing can occur in this population, and whether MRI may be used as a tool to assess bone healing and inform clinical decision making.
Design: Retrospective cohort.
Methods: Participants were elite Australian fast bowlers who sustained a lumbar spine stress fracture confirmed on MRI and had at least one subsequent MRI. Two radiologists independently reviewed all images.
Results: Thirty-one fractures from 20 male fast bowlers were reviewed. Median maximum fracture size was 6 mm (range 2–25 mm). Twenty-five fractures achieved bone healing, with a median 203 (IQR 141–301) days between the initial MRI (to confirm diagnosis) and the MRI when bone healing was observed. Fracture size and signal intensity of bone marrow oedema were positively associated with the number of days to the MRI when bone healing was observed ($r^2 = 0.245$, $p < 0.001$ and $r^2 = 0.292$, $p < 0.001$ respectively). Fractures which occurred at the same site as a previously united fracture took longer to heal than the first fracture (median 276 days to the MRI when bone healing was observed compared to 114 days for first fracture; $p = 0.036$).
Conclusions: Lumbar spine stress fractures in elite adult fast bowlers are capable of achieving complete bone healing, as demonstrated in the majority of bowlers in this study. Larger fractures, greater bone marrow oedema, and history of previous injury at the same site may require longer healing time which may be monitored with MRI.

Practical implications

- Lumbar spine stress fractures can achieve full bone healing in elite adult fast bowlers.
- Features of bone healing on MRI are a reduction in bone marrow oedema, bony sclerosis and reduction in the size of the fracture line.
- Larger fracture size, a greater extent of bone marrow oedema, and/or history of a previous fracture at the same site may require longer time to heal.
- Serial MRI may be of use to monitor fracture size, bone marrow oedema, and bone union to inform individual clinical management.

1. Introduction

Lumbar spine stress fractures result in the most game time missed due to injury in elite cricket fast bowlers with prevalence typically reported around 30% but has been reported as high as 67%.[1] Stress fractures in this population occur at the pars region of the vertebrae (junction of the pedicle, articular facets and lamina) which is susceptible to stress from repetitive lumbar extension, side flexion, and rotation of the bowling action.[2]

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Lumbar stress fractures in cricketers which do not fully heal are prone to recurrence, pain, and contralateral stress fracture.[3,4] Chronic non-union in athletic populations may increase the likelihood of surgery and lead to long-term complications such as spondylolisthesis, chronic back pain, and degenerative disease.[5] Given the prevalence of lumbar spine stress fractures in elite cricket fast bowlers, and potential long-term consequences, it is important to address both risk reduction and also how these injuries can be best managed when they occur. This paper will focus on the latter, specifically the radiological healing of lumbar spine stress fractures (termed 'bone healing' in this paper).

Stress fractures are understood to result from an imbalance between damage and repair of the bone.[6] Previous research on lumbar spine stress fractures in fast bowlers has focused on damage exceeding repair and consequent progression along the bone stress continuum from bone stress to stress reaction to incomplete stress fracture to complete fracture.[7] To date, regression along the continuum and bone healing has received little attention. Bone healing has been demonstrated in children and adolescents with lumbar stress fractures,[8] however further research is needed to establish whether this occurs in adults, particularly elite athletes.

Computed tomography (CT) has previously been regarded as the gold standard modality for diagnosing lumbar spine stress fractures,[9] and has also been advocated for follow-up imaging to assess bony union.[10] However CT cannot always differentiate active stress fractures from chronic non-united fractures, involves ionizing radiation, and is unable to detect early stage injury such as stress reaction.[11] Magnetic resonance imaging (MRI) has recently become the preferred imaging modality for the diagnosis of injuries of the lumbar spine from bone stress to stress fracture.[11,12] Thin slice 3D volumetric interpolated breath-hold examination (VIBE) sequence result in T1-weighted images with increased spatial resolution, improved image contrast, and increased signal to noise ratio resulting in similar sensitivity to CT in detecting lumbar stress farctures.[13] Given these strengths of MRI imaging, and the avoidance of ionising radiation, MRI is the most promising imaging modality to assess bone healing of lumbar spine stress fractures.

The purpose of this study is to review MRI of elite adult fast bowlers with history of a lumbar spine stress fracture for evidence of bone healing. The findings will determine whether a) bone healing can occur in this population, and b) MRI may be used as a tool to assess bone healing and inform clinical decision making in elite cricket fast bowlers.

2. Methods

Ethics approval was gained from an Institutional Ethics Committee (La Trobe University HEC18348). Participants were elite Australian fast bowlers who sustained an acute lumbar spine stress fracture with bone oedema and characteristic acute fracture appearance confirmed by MRI (as distinct from congenital or chronic defects), between 2012-2018. Inclusion criteria required participants to have a diagnostic MRI and at least one subsequent MRI at the same imaging clinic. The timing of follow up MRI were directed by the clinician(s) managing the individual case and consequently were not uniform. Fast bowler was defined as a bowler who delivers the ball at a medium or fast pace and to which the wicket keeper typically stands back from the stumps.

Two musculoskeletal trained Radiologists (R1 and R2) independently reviewed all the MRI and were blinded to clinical information. The fracture morphology was assessed on the T1 VIBE sequence using a dedicated reformatted sequence for each side of the patient. Fracture size was measured in millimeters superiorly to inferiorly in a direction perpendicular to the vertebral body endplates. On the follow up MRI the fracture was measured in the same location as the initial MRI. For the purposes of the study, bone healing was defined as no fracture line demonstrated on the T1 VIBE sequence. Bone marrow oedema (BMO) signal intensity was measured in the three locations using published methods adapted to use a region of interest area of 0.4 cm^2.[7] The region of interest area was selected to obtain a representative measure of both the intensity and extent of bone marrow oedema. Bone marrow oedema intensity was measured about the fracture site, contralateral site to the fracture, and the vertebral body one slice lateral to the basivertebral vein on the same side as the fracture.

All MRI were performed using standard lumbar spine sequences at the time, with 2 slightly different protocols captured in this study. Images prior to January 2018 (n = 61) were performed on a 3-T Siemens (Magnetom Verio I-class. Erlangen, Germany) using a dedicated spine coil with a sagittal, fat-saturated, three-dimensional (3D) gradient- echo, T1, volumetric interpolated breath-hold examination (VIBE) sequence (TR/TE of 7 ms/2.45 ms, 20 cm FOV, 2 mm slice thickness), and a sagittal short-tau inversion recovery (STIR) (TR/TE/inversion time (TI) of 5490 ms/53 ms/130ms, 30 cm FOV, and 3.5 mm slice thickness). Images performed from January 2018 (n = 11) were performed on a 3-T Siemens Magnetom Vida machine with a dedicated spine coil and sagittal T1FS 3D VIBE (TR/TE of 5.78/2.64 ms, 20 cm FOV and 1.5 mm slice thickness) and STIR (TR/TE of 3200 ms/41 ms, 26 cm FOV and 3.5 mm slick thickness) sequences. Images for seven injuries traversed both imaging protocols.

The first MRI confirming the lumbar spine stress fracture was denoted 'MRI 0' even if the fracture progressed on follow-up MRI. If a fracture was confirmed to have healed on imaging, any subsequent fracture in the same location was regarded as a new injury.

Descriptive statistics were used to summarise fracture and bone healing details. The number of cases is only reported for five or more cases to comply with ethics requirements. Fracture size and BMO signal intensity ratio were positively skewed, hence central tendency was calculated as the median and interquartile range (IQR).

The inter-rater reliability of subjective comments made by radiologists (presence/absence of sclerosis and the absence/decrease/stable/increase of BMO) are reported as the absolute number of comments in agreement or disagreement. The inter-rater reliability of fracture size and BMO signal intensity ratio was assessed using a two-way mixed, absolute agreement intra-class correlation coefficient (ICC). Qualitative interpretation of ICC values above 0 (random agreement) is ICC < 0.40 poor, ICC = 0.40–0.59 fair, ICC = 0.60–0.74 good, and ICC = 0.75–1.00 excellent.[14] Linear regression was used to illustrate the relationship between fracture size and BMO signal intensity ratio (mean of both radiologists) and days to the MRI where bony union was confirmed. Analysis was completed using Excel (Microsoft, 2016 MSO) and SPSS (version 25, IBM, Armonk, NY, USA).

3. Results

Thirty-one lumbar stress fractures from 20 male fast bowlers met the inclusion criteria. The median number of days between MRI for individuals was 112 (IQR 68–244). The mean age at the time of the MRI showing the initial lumbar spine stress fracture was 20 ± 4 years (range 15–31). Lumbar spine stress fractures occurred at the following levels: T12 (n < 5), L2 (n < 5), L3 (n = 5), L4 (n = 13), L5 (n = 9) with 21 fractures occurring on the contralateral side to the bowling arm, less than five fractures on the ipsilateral side and 7 fractures were bilateral. Fractures were located at the inferior pars-pedicle junction (n = 18), inferior pars (n = 9), inferior pedicle (n < 5), or junction of the pedicle and vertebral body (n < 5). Each lumbar stress fracture had a median of 1 (IQR 1–1.5; range 1–4) follow-up MRI following MRI 0.

Inter-rater reliability of fracture size (ICC 0.944, 95% CI 0.911–0.965) and BMO (ICC 0.844, 95% CI 0.762−0.900) were excellent. The median maximum fracture size was measured as 6 mm (IQR 5–8; range 3–25) by R1, and 6 mm (IQR 4–9; range 2–21) by R2. The median maximum BMO was measured as 2.4 (IQR 1.7–2.7; range 1.2–5.3) by R1, and 2.3 (IQR 1.5–2.9; range 1.0–5.9) by R2.

Following the initial MRI, five fractures progressed in fracture size before reducing. The median number of days between MRI 0 and largest fracture size observed was 76 (IQR 54–133) days (compared to 200 (IQR 89–284) days between MRI 0 and the first follow up MRI for injuries which were not observed to increase in fracture size). Four of the five fractures which increased in size had a simultaneous reduction in BMO, whilst one fracture showed increased BMO with increased fracture size. Both radiologists agreed that 25 fractures showed complete bone healing, five had not healed, and there was disagreement on one fracture. In addition to reduction of the fracture margins, other features of bone healing observed on MRI were a decrease or absence of BMO, observed in 23 fractures (74%, 95% CI 55–88%), and the presence of sclerosis, detected in 22 fractures (71%, 95% CI 52–86) agreed by both radiologists.

For the 25 agreed united fractures, median days between MRI 0 and the MRI showing complete bone healing was 203 (IQR 141–301). Six of these fractures had a MRI which showed incomplete healing prior to the MRI showing complete bone healing, which occurred at 170 (IQR 64–256) days since MRI 0. The size of the fracture was positively associated with the number of days to the MRI showing complete bone healing ($r^2 = 0.245$, $p < 0.001$). The highest BMO signal intensity ratio was positively associated with the number of days to the MRI showing complete bone healing ($r^2 = 0.292$, $p < 0.001$). The age of the bowler at MRI 0 was not associated with the number of days to the MRI showing complete bone healing ($r^2 = 0.009$, $p = 0.649$).

Five of the bowlers had a fracture which had radiological evidence of bone healing, then sustained a subsequent fracture at the same location. The subsequent fracture healed in most cases, but the time for bone healing for the second fracture was significantly longer than the first (median 276 days to the MRI showing complete bone healing compared to 114 days for first fracture; $p = 0.036$).

Five fractures in five bowlers did not have radiologically confirmed bone healing. These fractures were similarly characterised to those that healed with regards to age (23 ± 5 years; range 17–27), maximum fracture size (median 6 mm; IQR 6–8; range 5–18.5), and maximum BMO (median 2.4; IQR 1.5–3.3; range 1.0–4.2). The most recent MRI for each injury (median 97 (IQR 78–194) days since MRI 0 and median 61 (IQR 56–97) days since largest fracture) noted a reduction in fracture size (median −3.5 mm; IQR −4 to −2) and BMO (median −1.4; IQR −2.0 to −0.4).

4. Discussion

Lumbar spine stress fractures are a common and problematic injury for elite fast bowlers. Complete healing of such fractures may reduce the risk of deleterious short- and long-term consequences. This study demonstrated that the majority of lumbar spine stress fractures in elite adult fast bowlers can achieve complete bone healing. Five of the fractures which did not achieve complete bone healing during the study did show signs of healing and it is possible that some may have gone on to achieve healing with further time and follow up.

The size of the fracture and the severity of BMO were positively associated with the number of days to the MRI showing complete bone healing. This has two potential clinical implications. Firstly, diagnosis of lumbar spine injury earlier on the bone stress continuum (smaller size, less BMO) may require less time to heal than a more progressed injury. Secondly, quantifying the extent of BMO on MRI may provide information to the clinician regarding severity and anticipated time needed for bone healing. However, we caution that the linear regressions were weak (likely attributable to the timing of imaging and individual factors) and hence should not be used to *predict* the time required for bone healing.

All lumbar spine stress fractures in this study involved the inferior cortex, the majority at the inferior pars-pedicle junction, and extended superiorly with bone healing occurring in the reverse direction. The direction of fracture propagation and bone healing is consistent with prior research.[10] Five of the fractures showed initial increase in size of the fracture prior to bone healing which could be due to bone resorption and/or osteopenia as part of the bone healing process.[5] It is possible that this healing process involving an apparent increase in fracture size also occurred in some or all of the other fractures, however there was no earlier imaging for this to be observed. It is important for the clinician to be mindful that an initial increase in fracture size on MRI does not necessarily indicate deterioration or that the fracture will not go on to heal. However, it is also important for the clinician to consider whether the individual's sporting and non-sporting activities since diagnosis may have contributed to fracture progression.

The time-frame for complete bone healing of lumbar spine stress fractures may have occurred between approximately 170 and 200 days, however this was highly variable and can not be concluded from the nature of this study. Subsequent fractures at the same site as a previous fracture took longer to heal than initial fractures. It is important for clinicians to be aware that subsequent fractures may have longer bone healing and possibly return to sport timelines so that they can plan accordingly. It is possible that older age is a factor for longer union times for subsequent fractures,[15] however this would be a within-individual factor as age was not related to bone healing time across all fast bowlers in the study. The observed between-individual and within-individual variation in bone healing times may support the use of serial MRI to monitor bone healing to individualise clinical management.

A limitation of this retrospective study is that MRI were not performed prior to injury, and therefore it can not be confirmed with certainty that there were no pre-existing defects. Nevertheless, it is most likely that the stress fractures were acute from their appearance on MRI, ability to heal, and also findings from previous studies with baseline MRI which demonstrated that fast bowlers developed new stress fractures during a cricket season.[16–18] A further limitation is that MRI were only performed as directed by the treating clinician(s) and consequently timing and number of follow up MRI varied. As such, it is not possible to determine when in this period between MRI that union of the fracture occurred, and hence union times may be over-estimated. Similarly, it is noted that some of the five without documented bone healing had their last follow up MRI for this study sooner than the median healing time. These bowlers may have gone onto bone healing if followed for long enough with MRI post injury. Consequently, this paper cannot report what proportion of lumbar stress fractures in cricket fast bowlers achieve bone healing, however it is at least 83% (95% CI 65–94%; 25 of 30 agreed cases). The study population were all elite male fast bowlers, therefore the findings may not relate to other athlete or patient populations. The findings of this study may be extended by further research including baseline MRI, regular serial MRI post-injury, and other populations.

5. Conclusion

Lumbar spine stress fractures are a problematic injury for elite fast bowlers, and fracture healing may be important for short- and long-term successful outcomes. This study demonstrated that lumbar spine stress fractures in elite adult fast bowlers can achieve complete bone healing, and the majority did in this cohort. Bone healing is slow and the time to achieve complete bony union varies between individuals. The size of fracture and extent of BMO are positively associated with bone healing time. Therefore, MRI may assist clinical management of lumbar spine stress fractures in elite fast bowlers to ensure complete bone healing before returning to bowling, however this should be further evaluated with consideration of clinical outcomes.

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