



Bony stress in the lumbar spine is associated with intervertebral disc degeneration and low back pain: a retrospective case–control MRI study of patients under 25 years of age

Daniel Chepurin¹ · Uphar Chamoli^{2,3} · Kyle Sheldrick² · Samuel Lapkin⁴ · David Scott⁵ · Jeff Kuan⁶ · Ashish D. Diwan²

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Abstract

Purpose Abnormal stress in the lumbar vertebra, also known as bony stress, can be a precursor to degenerative changes which may manifest as low back pain (LBP). However, the prevalence of bony stress in the lumbar spine and its relationship with degenerative changes and LBP is unclear. The purpose of this study was to evaluate the prevalence of bony stress in the lumbar spine and its relationship with intervertebral disc (IVD) degeneration, facet osteoarthritis and LBP in patients under 25 years of age.

Methods A retrospective case–control study of 130 patients under 25 years of age was conducted from a population of 493 patients who had lumbar MRI across three imaging centres over three years. A cohort of 55 consecutive patients with bony stress was identified. A control group of consecutive patients ($n = 75$) without bony stress was also selected from the population.

Results Bony stress was prevalent in 11% (95% CI [8.4–14.5%]) of patients and was not diagnosed in 36% (95% CI [22–55%]) of these cases. Patients with bony stress had over twofold (OR 2.3, 95% CI [1.1–4.8]) and fivefold (OR 5.3, 95% CI [2.11–13.3]) higher likelihood of having IVD degeneration and LBP, respectively, when compared with the control group. Bony stress was not found to be associated with facet osteoarthritis.

Conclusion Bony stress in the lumbar spine was prevalent in 11% of patients under 25 years of age. It was commonly undiagnosed in radiology reports (not reported in 36% of the cases). Being significantly associated and with an increased likelihood of IVD degeneration and LBP, we posit that bony stress is likely a symptomatic and clinically meaningful diagnostic entity in the assessment of LBP.

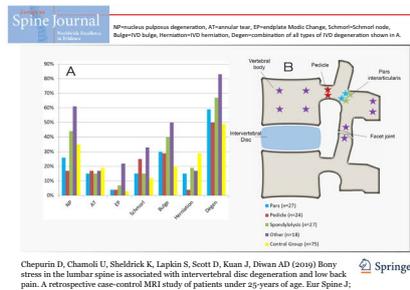
Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.

Spine Journal
Key points

1. The purpose of this study was to evaluate the prevalence of bony stress in the lumbar spine and its relationship with intervertebral disc (IVD) degeneration, facet osteoarthritis, and low back pain (LBP) in patients under 25-years of age.
2. A retrospective case-control study of 130 patients under 25-years of age was conducted from a population of 493 patients who had lumbar MRI across three imaging centres over three years.
3. A cohort of 55 consecutive patients with bony stress and a control group of 75 consecutive patients without bony stress was selected from the population.

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Take Home Messages

1. Bony stress was prevalent in 11% of the population of patients under 25-years of age as seen on lumbar MRI scans, and was not reported in the radiologist's report in 36% of the cases.
2. The odds of having IVD degeneration were 2.3 times higher in the bony stress group compared with the control group.
3. The odds of having LBP as an indication for lumbar MRI were 5.3 times higher in the bony stress group compared with the control group.

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Keywords Bony stress · MRI · Lumbar spine · Disc degeneration · Facet osteoarthritis

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Extended author information available on the last page of the article

Introduction

Spondylolysis, a bony defect in the pars interarticularis of the neural arch, occurs in nearly 6% of the general population, typically during childhood and adolescence [1]. Accumulation of stress reactions in the pars region of the vertebra may lead to unilateral or bilateral spondylolysis [2]. Intervertebral disc (IVD) degeneration is thought to be associated with stress shielding and osteoporotic vertebral fractures [3, 4]. Adolescents and young adults present as optimal cases to study the interaction between the bony elements and the viscoelastic IVD due to fewer age-related confounding factors [5].

Bony stress, which is essentially a micro-fracture of the trabecular bone, may accumulate over time and result in an overt fracture. Hollenberg et al. (2001) were the first to propose a classification scheme based on magnetic resonance imaging (MRI) to grade bony stress reaction in the lumbar pars interarticularis region [6]. The present consensus on the characterisation of bony stress on MRI is hyperintensity on T2-weighted imaging with the corresponding hypointensity on T1-weighted imaging (Fig. 1), or an unambiguous presence of lumbar spondylolysis [7–10]. Bony stress is thought to either alter force transmission throughout the IVD or be brought about due to the altered force distribution through the IVD following IVD degeneration [7].

The IVD is the largest avascular organ in the human body, relying entirely on diffusion for nutrition and elimination of cellular wastes. This retards the biological repair and regeneration process of the IVD and also makes it susceptible to be overtaken by degeneration if it experiences trauma or repeated forces beyond a threshold [11,

12]. Previous studies have shown an increased prevalence of IVD degeneration in the presence of bony stress [7, 8, 13–16]. However, a case–control study of young subjects has not been conducted to evaluate this relationship. Whether the progressive IVD changes are a source of low back pain (LBP) or the bony stress is the primary cause of LBP remains unclear. Worldwide, the cause of LBP is unclear in about 90% of the patients, and such cases are commonly referred to as non-specific LBP [17, 18].

The prevalence of bony stress and its relationship with LBP and IVD degeneration in the lumbar spine is not well understood. The present study aimed to address this gap in evidence by assessing the prevalence of bony stress in the lumbar spine and its relationship with IVD degeneration, facet osteoarthritis, and LBP in patients under 25 years of age.

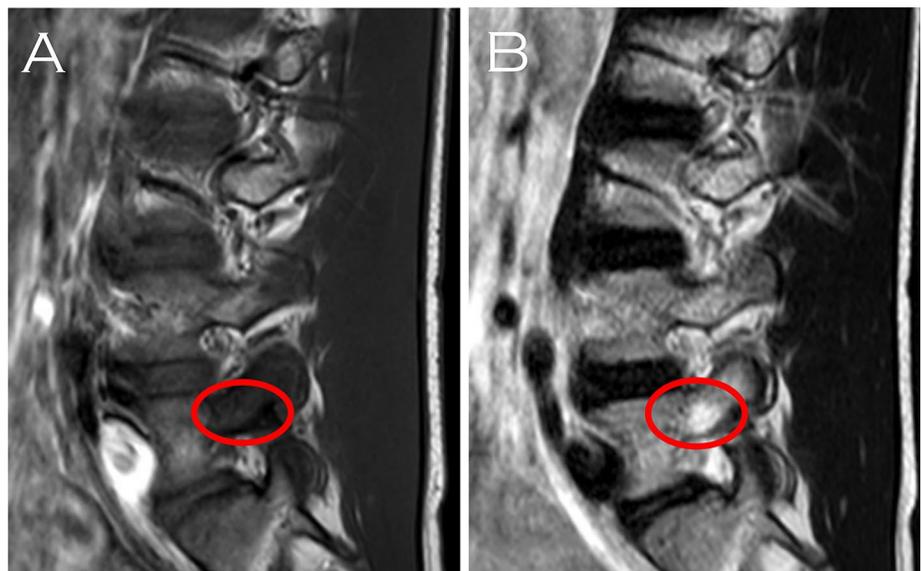
Materials and methods

Ethical approval was obtained from the Human Research Ethics Committee of the University of New South Wales (NRR-HC180423) for retrospective collection of anonymised patient’s lumbar MRI scans, radiology reports, and demographic data from the digital archives of Healthcare Imaging Services (St. Leonards, NSW, Australia).

Patients and methods

The study was conducted as a retrospective review of MRI data, radiology reports, and demographic data of patients below the age of 25 years who had routine lumbar MRI from three radiology centres in Sydney (Australia) between March 2015 and March 2018. The search yielded data for

Fig. 1 A sagittal slice from the magnetic resonance imaging (MRI) of a patient with bony stress in the L5 pedicle as defined by bony oedema. Oedema (within the red circles) is represented by **a** hypointensity on T1-weighted MRI and **b** corresponding hyperintensity on T2-weighted MRI



493 patients. The most recent MRI scan was used if multiple scans of the same patient were available in the database. All patients in the population were consecutively studied for the presence of bony stress. Patients with any vertebral body fracture or a fracture in the posterior lumbar spine (excluding spondylolysis) or previous history of lumbar surgery were excluded from this study.

Data collection

MRI scans were assessed, and corresponding radiology reports were read by the first author (DC). DC was trained by a board-certified radiologist (JK) with over 16 years of experience in evaluating lumbar MRI scans. Bony stress was defined as hyperintensity on T2-weighted MRI with hypointensity on corresponding T1-weighted MRI as described previously [7–10]. MRI data points were collected before reading the radiology report. If bony stress was present on MRI scans but not mentioned in the radiology report, it was classified as a missed diagnosis. All the radiologists who prepared the reports were board-certified working at the three radiology centres. The presence of LBP was defined as the inclusion of “LBP” by the referring doctor as part of clinical indication for MRI. IVD degeneration was defined as the presence of at least one of the following: nucleus pulposus degeneration, annular tear, endplate Modic changes, Schmorl’s node, IVD bulge or IVD herniation (protrusion, extrusion or sequestration) [9, 19–24]. Nucleus pulposus degeneration was defined as Pfirrmann grade ≥ 3 [7]. Facet osteoarthritis was defined as a reduction in the joint space between each facet, irregular facet joint surface, presence of osteophytes, cysts or excessive facet joint fluid (space ≥ 2 mm) [25]. Data points for ten patients were also measured by a second rater (KS) for evaluating inter-rater reliability, and for a second time 3 weeks after the first collection by the first rater (DC) for evaluating intra-rater reliability.

Statistical analyses

Statistical analyses were conducted using a commercially available software tool SPSS (version 20, IBM Corporation, Armonk, USA). The level of significance was set at 5% ($\alpha = 0.05$). Inter-rater and intra-rater reliabilities were assessed using Cohen’s kappa coefficient (κ). Kappa value in the ranges ≤ 0 , 0.01–0.2, 0.21–0.4, 0.41–0.6, 0.61–0.8 and 0.81–1 indicated no agreement, none to a slight agreement, fair agreement, moderate agreement, substantial agreement and almost perfect agreement, respectively [26]. Exact Poisson test was used to calculate the prevalence and missed diagnosis rates. Pearson’s Chi-squared test was used to assess the independence of the association between bony stress and IVD degeneration, facet osteoarthritis, and the presence of LBP. The strength of association between bony

stress and IVD degeneration, facet osteoarthritis, and presence of LBP was measured using Phi and Cramer V. Odds ratio (OR) was calculated to estimate risk and presented with 95% confidence intervals (CIs). Binary logistic regression models were used to analyse the confounding status of IVD degeneration in the analysis of the association between bony stress and the presence of LBP.

Results

Demographic details

Table 1 shows the patient demographic and clinicoradiological information. Out of 493 patients included in the study population, 55 met the criteria for bony stress. Seventy-five patients without bony stress were chosen consecutively from the population as controls to compare with the cohort of bony stress patients. Fourteen patients with bony stress had spondylolisthesis, compared with two in the control group.

Inter-rater and intra-rater reliability

Table 2 shows the inter-rater and intra-rater reliability results for IVD degeneration and facet osteoarthritis.

Prevalence

The prevalence of bony stress in the overall population was around 11% (55/493) (95% CI [8–15%]). The reporting radiologist did not diagnose bony stress in around 36% (20/55) (95% CI [22–55%]) of the cases. Of the 55 patients with bony stress, 48 had bony stress at one lumbar level, and seven had bony stress at two lumbar levels. There was a higher prevalence of bony stress and IVD degeneration in the lower lumbar levels (Table 1). Bony stress was mostly present in the pars interarticularis and pedicle but was also found in other regions, with some patients having bony stress across multiple regions (Table 3).

IVD degeneration and bony stress

IVD degeneration was present in 38/55 (69%) bony stress patients and 37/75 (49%) control patients. Bony stress and IVD degeneration were weakly positively associated ($\chi^2 = 5.075$, $P = 0.024$, Phi and Cramer V = 0.198). The odds of having IVD degeneration were 2.3 times higher in bony stress cases when compared with the control group (OR 2.3,

Table 1 Patient demographic and clinicoradiological information

Parameter	Bony stress	Controls
Number of patients	55	75
Age (years)	17.6 ± 3.9 (7–24)	18.7 ± 4.01 (12–24)
Gender (% M/F)	71/29	45/55
Lumbar levels with bony stress (total)	62	–
L1	1 (2%)	–
L2	1 (2%)	–
L3	5 (8%)	–
L4	10 (16%)	–
L5	45 (73%)	–
IVD degeneration (number of patients)	38 (69%)	37 (49%)
Lumbar levels with IVD degeneration (total)	71	72
L1/L2	4 (6%)	4 (6%)
L2/L3	6 (8%)	6 (8%)
L3/L4	9 (13%)	10 (14%)
L4/L5	20 (28%)	21 (29%)
L5/S1	32 (45%)	31 (43%)
Facet osteoarthritis	13 (24%)	29 (39%)
LBP indication for MRI	45 (87%)	40 (55%)

IVD intervertebral disc, LBP low back pain

Table 2 Cohen’s kappa (κ) coefficients for intervertebral disc degeneration and facet osteoarthritis

	Intervertebral disc degeneration	Facet osteoarthritis
Inter-rater	Moderate ($\kappa=0.60$)	Substantial ($\kappa=0.61$)
Intra-rater	Moderate ($\kappa=0.56$)	Almost perfect ($\kappa=1.00$)

Kappa value in the ranges ≤ 0 , 0.01–0.2, 0.21–0.4, 0.41–0.6, 0.61–0.8 and 0.81–1 indicated no agreement, none to a slight agreement, fair agreement, moderate agreement, substantial agreement and almost perfect agreement, respectively

Table 3 Region-wise distribution of bony stress in the lumbar vertebra

Region of bony stress	Number of cases
Pars interarticularis	27
Pedicle	24
Spondylolysis	27
Others	
Lamina	7
Vertebral body	4
Facet	3
Spinous process	3
Transverse process	1

Spondylolysis, whilst affecting the pars interarticularis, was included as a unique region

95% CI [1.1–4.8]). The distribution of IVD degeneration by bony stress regions is shown in Fig. 2.

Facet osteoarthritis and bony stress

Facet osteoarthritis was present in 13/55 (24%) of the bony stress patients and 29/75 (39%) of the control patients. Bony stress and facet osteoarthritis were not significantly associated ($\chi^2=3.278$, $P=0.07$, Phi and Cramer V=0.159). The odds of having facet osteoarthritis in bony stress patients were nearly half when compared with the control group (OR 0.5, 95% CI [0.2–1.1]).

Low back pain and bony stress

LBP indication for MRI was present in 45/52 (87%) bony stress patients and 40/73 (55%) control patients. Bony stress and LBP indication for MRI were strongly positively associated ($\chi^2=14.063$, $P=0.000$, Phi and Cramer V=0.335). The odds of having LBP were 5.3 times higher in bony stress patients when compared with the control group (OR 5.3, 95% CI [2.1–13.3]). Five patients did not have clinical indication available (three bony stress patients and two control patients). A binary logistic regression analysis was conducted to include IVD degeneration as a covariate. IVD degeneration had an insignificant confounding effect on LBP indication for MRI (OR 1.0, 95% CI [0.4–2.2], $P=0.96$).

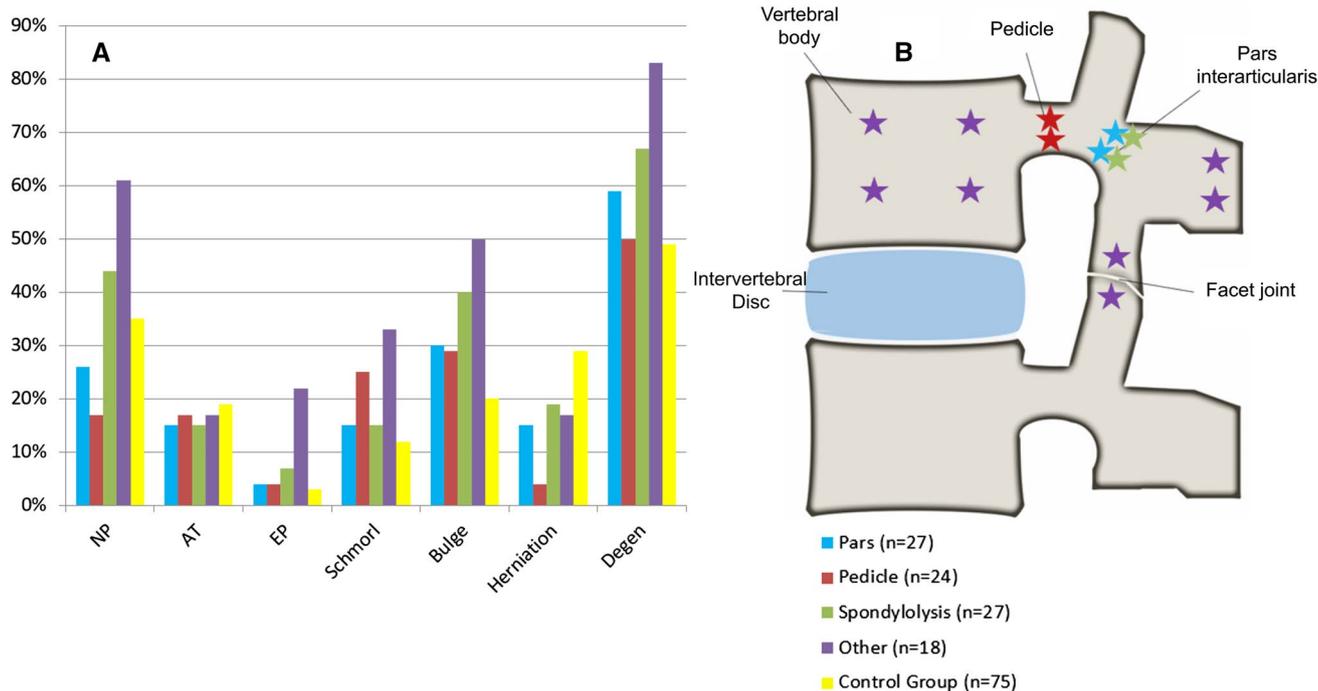


Fig. 2 Graphical representation of intervertebral disc (IVD) degeneration across various regions of bony stress in the lumbar vertebra. **a** Distribution of various types of IVD degeneration and total IVD degeneration against the associated regions of bony stress and the control group. “Degen” was counted as present or absent; even if a patient had multiple types of IVD degeneration, it was counted as present for “Degen” count. **b** Corresponding region of bony stress

by matching the colour on a representation of the sagittal lumbar spine (not shown: lamina and transverse process). “Other” regions include lamina, vertebral body, facets, spinous process, and transverse process. NP=nucleus pulposus degeneration, AT=annular tear, EP=endplate Modic change, Schmorl=Schmorl’s node, Bulge=IVD bulge, Herniation=IVD herniation, Degen=combination of all types of IVD degeneration shown in **a**

Discussion

To our knowledge, this is the first case–control study to report on the prevalence of bony stress in the lumbar spine of individuals under 25 years of age and also the association between bony stress and various clinicrodiological variables. The relatively young patient cohort in this study ensured that age-related confounding factors were kept to a minimal.

Our results showed that the bony stress was significantly associated with IVD degeneration and LBP, but not with facet osteoarthritis. Prevalence of bony stress in this consecutively selected population of <25-year-olds was approximately 11%. The reporting radiologist did not diagnose bony stress in a third of the cases. Spondylolysis has been reported to be missed on MRI in up to 64% of the cases, but bony oedema was not included in these studies [27–29]. Clinicians may not look for bony stress in the MR scans of their LBP patients if bony stress has not been recognised as a potential contributor to pain and IVD degeneration. Our results show an increased likelihood of IVD degeneration and LBP in the presence of bony stress. By showing a positive association between bony stress and IVD degeneration in a case–control

study, these results highlight the importance of increased awareness, early diagnosis and prevention of progression.

The odds of having IVD degeneration were 2.3 times higher in the bony stress group compared with the control group. Previous studies on bony stress have mostly described a cohort of patients, reporting rates of IVD degeneration in the presence of bony stress rather than making comparisons with a control group of patients without bony stress [6, 8, 13–16]. Few studies have examined the relationship between bony stress and IVD degeneration in the lumbar spine; one of which used the IVD adjacent to a lumbar vertebra without bony stress in the same patient as the control group [7].

The odds of having LBP were 5.3 times higher in the bony stress group compared with the control group. IVD degeneration was found not to be confounding these results. Most of the previous studies have examined only the symptoms of spondylolysis [30–36], as opposed to the broader definition of bony stress. The results from the present study suggest the possible contribution of micro-trabecular fracture in creating bony oedema that may manifest as LBP. The present study evaluated LBP only as qualitative and clinician-rated; however, the results may still be useful as the study evaluated the relationship between bony stress

and LBP in a population of patients under 25 years of age who warranted a lumbar MRI. Clinicians managing LBP cases may not reach a definitive diagnosis in over 90% of the cases (non-specific LBP) [18]. The management of non-specific LBP cases with the overuse of imaging, opioids and surgery is a widespread problem and an ongoing challenge for healthcare providers [37]. Our results suggest that bony stress may be implicated in independently causing LBP. If the findings are implemented in routine MRI and clinical assessments of LBP patients, these may help in decreasing the number of non-specific LBP diagnosis.

Bony stress was not significantly associated with facet osteoarthritis; however, an OR of 0.5 is suggestive of a negative association. Whilst it is not clear whether abnormal load distribution is a cause of bony stress, cadaveric and finite-element modelling studies have shown that the bony vertebra is the “weak link” of the lumbar spine and any minor damage to it can lead to progressive structural changes in the adjacent IVDs [38–40]. A more compliant region (or presence of bony stress) of the vertebra may cause more force transmission through the IVD, whilst a stiffer region of bone may cause more force transmission through the facets. This hypothesis may help explain the negative association between bony stress and facet osteoarthritis found in the present study, but needs further investigation using a cadaveric or a finite-element model of the lumbar spine.

Certain limitations to this study were noted. The study design is retrospective cross-sectional, and hence, the results do not speak to trends over time. Although the study population was multi-centric (three MR imaging facilities across Sydney), factors such as socioeconomic status, cultural factors, health status and prevalence of disease would all differ, both amongst the three centres and between the study population and the wider population. The population studied only included those who warranted a lumbar MRI; hence, the true nature and prevalence of bony stress, especially of those not presenting to a clinician, or those managed without imaging, are difficult to examine. All patients were under 25 years of age, and there was a non-uniform gender spread between groups and hence some limitations for generalisability of results. Clinical indication for MRI could not be obtained for five patients, and this may affect the reliability of LBP results. The nature and duration of LBP were not accessible. Possibly, small sample size may underestimate some effects as no power calculations were conducted.

Conclusions

In conclusion, bony stress was present in 11% of patients under 25 years of age undergoing lumbar spine MRI and was not diagnosed in 36% of cases where it was present. The odds of having IVD degeneration were 2.3 times

higher in the bony stress group compared with the control group. Similarly, the odds of having LBP were 5.3 times higher in the bony stress group compared with the control group. These results suggest that “bony stress” is likely to be a symptomatic and clinically meaningful diagnostic entity and emphasise the need for its proper diagnosis, minimising harm from unnecessary investigation and preventative management.

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Compliance with ethical standards

Ethical approval Ethical approval was obtained from the Human Research Ethics Committee of the University of NSW (NRR-HC180423) prior to conducting this study.

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Affiliations

Daniel Chepurin¹ · Uphar Chamoli^{2,3} · Kyle Sheldrick² · Samuel Lapkin⁴ · David Scott⁵ · Jeff Kuan⁶ · Ashish D. Diwan²

✉ Uphar Chamoli
u.chamoli@unsw.edu.au

¹ Faculty of Medicine Nursing and Health Sciences, Monash University, Clayton, VIC, Australia

² Spine Labs, Department of Orthopaedic Surgery, L3 WR Pitney Building, St. George and Sutherland Clinical School, Faculty of Medicine, The University of New South Wales, St. George Hospital Campus, Kogarah, NSW, Australia

³ School of Biomedical Engineering, Faculty of Engineering and Information Technology, University of Technology Sydney, Ultimo, NSW, Australia

⁴ Faculty of Science, Medicine and Health, University of Wollongong, Wollongong, NSW, Australia

⁵ Department of Medicine, School of Clinical Sciences at Monash Health, Monash University, Clayton, VIC, Australia

⁶ St. George MRI, Healthcare Imaging, Kirk Place, Kogarah, NSW, Australia