Are MRI Scans A Good Clinical Tool To Diagnose Mechanical Factors For Low Back Pain?

Gary Dougill[a *], Neil D. Reeves[b], Christine L. Le Maitre[c], Kirstie D. Andrews[a], Glen Cooper[d]

[a] *School of Engineering, Manchester Metropolitan University, John Dalton Building, Manchester, M1 5GD, United Kingdom.*
[b] *School of Healthcare Science, Manchester Metropolitan University, John Dalton Building, Manchester, M1 5GD, United Kingdom.*
[c] *Biomedical Research Centre, Sheffield Hallam University, Sheffield, S1 1WB, United Kingdom.*
[d] *School of Mechanical, Aerospace and Civil Engineering, University of Manchester, Manchester M13 9PL, United Kingdom.*
[*] *Corresponding author, g.dougill@mmu.ac.uk*

Abstract

Clinicians attempting to diagnose low back pain (LBP) may use medical imaging to identify mechanical initiators such as disc bulging, protrusion and herniation leading to nerve impingement or other structural concerns. However current understanding of spinal posture is based on studies conducted in the relaxed supine position and/or with loading limited to bodyweight. However, some patients only have lower back pain during activities of daily living where significant changes in spinal posture occur and loading increases beyond that typical of imaging tests conducted in supine positions. This study investigates the differences between MRI images obtained in supine and standing positions, with or without additional loading to determine mechanical initiators which may be missed in patients who present pain during activity but not when at rest. Lumbar lordotic curvature was investigated using MRI imaging in 10 asymptomatic male subjects in three conditions: supine, standing and standing plus 12kg additional load. A number of key changes were seen in lordotic curvature between positions, 12 kg loading in a standing position resulted in a 17-42% increase in lordotic angle in the L1/L2 through L4/L5 discs when compared with the standing position ($p > 0.05$) and up to 71% increase compared with relaxed supine position ($p = 0.05$). L5/S1 lordotic angle was 21% lower in the loaded group relative to the supine baseline ($p = 0.05$) but was unchanged relative to the standing position. Pelvic angle between the S1 vertebrae and the horizontal plane was not significantly altered by MRI position. These results suggest that clinicians should be aware that MRI scans taken in the supine position may not indicate mechanical factors which cause low back pain during activities of daily living. Further investigation is required to determine whether loaded MRI positions are able to differentiate between degenerative changes within asymptomatic and symptomatic patients.

Key Words

Spine; back pain; magnetic resonance imaging; medical imaging; clinical diagnosis; loading; posture; intervertebral disc.

Introduction

Low back pain (LBP) is an increasing public health concern [1–3] and is considered to be a substantial burden on society [4]. Acute injury and/or chronic degeneration of the IVD has been linked with long-term back pain [5] and biomechanical changes in the lumbar spine have been investigated due to their link with LBP [5–8].

Magnetic Resonance Imaging (MRI) is an increasingly common diagnostic tool which can detect causes of back pain such as herniated discs [9]; however load magnitude, load time and spinal posture are significant factors in disc height loss and disc bulging [10,11] and therefore the lack of loading in relaxed supine images may conceal or reduce mechanical causes of pain such as disc narrowing or nerve impingement [12,13].

A number of previous studies have observed the effects of loading up to and including bodyweight on lumbar spinal posture relative to relaxed supine baselines [13–16]. The majority of these studies have been conducted with participants in the supine position and loading being applied by means of a compression device; however Hioki *et al.* investigated the effect of participants being in the standing position observing that certain patients who present pain whilst standing do not suffer whilst lying down [13], underlining the importance of examining spinal posture in the standing position.

Activities of daily living (ADLs) are known to increase loading on the lumbar spine beyond that in the supine or standing positions [17–19] and therefore MRI in a clinical setting may not capture spinal posture that is symptomatic of pain during activities as common as walking or standing up from a chair, even when conducted in the standing position. The present study intended to investigate changes in lumbar spinal posture at loading greater than bodyweight alone, simulating simple ADLs such as walking, sitting or carrying heavy bags.

Methods

Ten male participants aged 22 to 32 years (mean 27 years), 167 to 195 cm (mean 179 cm) and 66.3 to 93.2 kg (mean 77.6 kg) with no history of back pain or injury took part in the study. Informed consent was obtained prior to testing and all work was approved by and conducted in accordance with guidelines set by the Manchester Metropolitan University Faculty of Science and Engineering ethics board. Male asymptomatic participants were used to minimise natural variation in lumbar lordosis observed in women of childbearing age [20] or due to pre-existing injuries.

Participants underwent three scans with position and loading shown in Table 1. During the additional loading scan participants held two 6 kg, non-ferrous hand weights for a total of 12 kg of additional loading.

Each participant was assessed between 10 am and midday having avoided strenuous exercise or lifting but otherwise having completed their typical routine, previous studies where subjects have undergone rest periods immediately prior to scanning have shown high levels of strain [13] which may not be reflective of true ADLs.

Scan	Body Position	Loading
1	Supine	No Additional Load Applied
2	Standing	No additional Load Applied
3	Standing	12 kg Additional Loading

Table 1 - Participant Body Position and Loading State for Each of Three MRI Scans.

Subjects were scanned using a positional 0.25 Tesla MRI scanner (G-Scan Esaote, Genoa). Scan settings were optimised during preliminary testing in a compromise between multiple factors including scan time, subject comfort, image resolution and accurate capture of mid-sagittal plane. A T1-weighted spin echo was used with repetition and echo times of 440 ms and 18 ms respectively as these produced a high contrast between vertebrae and surrounding tissues which was required to take accurate measurement of disc height. Slice thickness and inter-slice gap affect image resolution with small values resulting in higher resolution images but requiring longer scan times, 5 mm was chosen for both as an optimum compromise between the contradictory considerations.

Two measurements of spinal posture were taken from the mid-sagittal image in each position of every participant. First, the adjacent vertebral angle was measured as the angle between inferior and superior facets of adjacent vertebrae from L1/L2 through L5/S1, second, pelvic angle was measured as the angle between the superior facet of L5 and the horizontal body plane (Figure 1).

Results were analysed using a repeated measures, linear mixed model approach with an autoregressive repeated covariance structure to determine whether body position and loading were significant factors in mean adjacent vertebral angle.

Results

Adjacent Vertebral Angle

Mean adjacent vertebral angle (Θ1) was reduced by 5% in the standing condition (7.9 degrees SD ± 1.7) compared with supine baselines (8.4 ± 1.6 degrees). Mean angle was measured as 9.4 ± 1.9 degrees in the loaded standing position, a 12% and 19% increase over supine and standing positions respectively. Using a linear mixed models approach, the effects of body position ($F = 3.41$, $p < 0.05$) and vertebral pairing ($F = 46.5$, $p < 0.0005$) were found to be significant factors in vertebral angle. In each of the three upper vertebral pairs (L1/L2-L3/L4) disc angle increased from supine to standing to loaded (Table 2**Error! Reference source not found.**, Figure 2) whereas in the lower two pairs, adjacent vertebral angle was lowest in the standing position, particularly at the L5/S1 level where standing angle was 21.5% lower in the standing position relative to supine.

Vertebrae Pair	Position	Mean Angle (Degrees)	Relative Change Over Supine (%)	Number of samples, N	Std. Deviation (Degrees)
L1/L2	Supine	3.6		8	2.3
	Standing	3.9	8.3	10	1.4
	Loaded *	5.4**	50	10	2.9
	Average	4.4		28	2.3
L2/L3	Supine	4.8		10	1.9
	Standing	6.3	31.25	10	2.4
	Loaded *	8.2**	70.8	10	3.3
	Average	6.4		30	2.9
L3/L4	Supine	7.7		10	2.5
	Standing	8.3	7.8	10	2.6
	Loaded *	10.4**	35.1	10	3.6
	Average	8.8		30	3.1
L4/L5	Supine	10.4		10	2.9
	Standing	9.8	-5.8	10	2.5
	Loaded *	11.6**	11.5	10	3.3
	Average	10.6		30	2.9
L5/S1	Supine	14.4		10	3.3
	Standing	11.3	-21.5	10	4.3
	Loaded *	11.4**	-20.8	10	2.2
	Average	12.4		30	3.6

*Table 2 - Mean adjacent vertebral angle between each vertebrae pair at each level across all participants. *Loaded indicates subjects were in a standing position holding an additional 12kg load. **results indicate a significant change from the supine condition (p<0.05).*

Pelvic Angle

Mean pelvic angle (Θ2) was not significantly different ($p \geq 0.05$) in any of the three positions with mean angles of 36.1 ± 6.2 degrees in the supine position, 36.3 ± 6.4 degrees in the standing position and 33.1 ± 6.4 degrees in the loaded position respectively (Figure 3).

Discussion

Understanding the mechanical response of the spine has previously been identified as an area of interest to spinal health and injury [21]. Past studies investigated the effects of loading on the spine up to and including bodyweight loading [13–16,22]; however most activities of daily living result in loading on the lumbar spine in excess of that during standing alone [17–19] and loading and spinal posture have been identified as key factors in disc height loss and bulging, potential mechanical factors in back pain [10,11].

The present study subjected participants to loading greater than that of bodyweight alone by asking them to hold two 6 kg hand weights during a standing MRI scan of their lumbar spine. The 12 kg loading represented an increase of between 12.9 and 18.1% of participant's bodyweight, an increase over loading in the neutral standing position typical of activities such as sitting upright (10%), walking (30%) and directly representative of tasks such as holding heavy shopping.

In the four upper lumbar discs, L1/L2 – L4/L5, the increased loading resulted in an increased lordotic angle between adjacent vertebrae of between 17-42% when compared with either the standing position and up to 71% when compared with the relaxed supine position. In the lower L5/S1 disc lordotic angle was reduced in both the standing and added load positions, a trend that has been observed in previous studies [13,16]. Pelvic angle between S1 and the horizontal plane was lower in the upright position but this change was not significant ($P > 0.05$).

Clinicians sometimes make diagnosis on the cause of low back pain based on MRI scans taken in the supine or standing position. From the results of this study it shows that MRI scans may underestimate vertebrae rotation (which may cause disc bulging and nerve impingement) due to medical scan postures and loading being different from activities of daily living when pain occurs.

The results of this study provide information on the trends of lumbar spinal posture when subjected to loading that is greater than bodyweight alone that is clinically relevant to those studying and predicting the behaviour of the spine in relation to activity or postures different to those performed in medical scans. Clinicians attempting to diagnose mechanical factors in patients with LBP or radiating leg pain should be aware that the adjacent vertebral angles observed in MRI scans may be significantly increased in the L1/L2 – L4/L5 region during other activities or postures than those adopted during the MRI scan. The increasing lordosis of the lumbar spine previously observed between relaxed/supine and bodyweight/standing loading continue when increased loading is applied suggesting that load is a key determinant of spinal response during activity. In a clinical setting using relaxed supine (or standing) MRI scans it is possible that mechanical factors in LBP that affect patients during activities of daily living are not observable during diagnosis or present in a reduced manner, which could hamper true representation of the spine.

Although the present study goes beyond previous work in applying loading greater than bodyweight the changes observed between supine and standing can be compared with the literature. Several previous studies which have compared spinal posture under loading, whether in the supine or standing positions have demonstrated similar results to the present study. Kimura *et al.* axially loaded participants in the supine position [16] whilst Wood *et al.* and Hioki *et al.* scanned participants in the standing position [13,23].

In all three studies mean adjacent vertebrae angle was observed to increase from supine to bodyweight loading through joints L1/L2 to L4/L5 by between 1 and 3 degrees and decrease in the L5/S1 joint by 1 and 4 degrees. These results closely mirror the present study with the exception of the L4/L5 joint which was observed to decrease by 0.6 degrees in the present study compared with an increase of 1 degree in both Kimura *et al,* and Wood *et al.* [16,23].

Other factors affecting the reliability of using MRI images are the scan times, the time the patient is in the scanning posture or the activity the patient has performed immediately before the scan. The intervertebral disc is a viscoelastic material meaning that higher magnitude adjacent vertebral angular changes are expected the longer the participant is in a loaded position. Alternative imaging techniques such as X-Ray, CT and fluoroscopy may have the potential to reduce imaging time or reduce the postural constraints of imaging equipment thereby reducing the effects of disc creep and participant discomfort but the increased risks of ionising radiation mean that these options may not always be suitable.

This study was limited by the total additional loading and the method of application of loading due to several factors. The internal dimensions of the MRI scanner precluded the use of weighted vests or backpacks which may have been more comfortable and allow higher loading to be applied than requiring participants to hold weights. Previous work has also used methods which apply loading through the shoulders in similar fashion to that of holding weights [13,14,16].

Whilst results from previous work for supine and standing postures are broadly consistent with the present study, observed differences in the L4/L5 joint may be a result of varying participant populations. All three previous studies which compared spinal posture in unloaded and loaded states used mixed sex participant groups [13,16,23], lumbar lordosis is affected by a range of factors including sex and is particularly pronounced in women of childbearing age [24] and the inclusion of female participants is likely to affect results.

Wood *et al.* benefits from a large number of study participants but specifically targeted older subjects and those suffering from low back pain. Fifty participants in the asymptomatic group had a mean age of 40.1 years whilst a further 50 participants had a history of ≥ 6 weeks of “mechanical lower back pain” and a mean age of 44 years [23]. Age is known to be a significant factor in spinal health, in particular the intervertebral disc to the extent that ageing is often indistinguishable from the effects of disc degeneration [25].

Kimura *et al.* included asymptomatic subjects aged 22-36 years [16] but the 67 kg mean weight and 170 cm height of subjects is both light and short compared with typical adults even when accounting for the female participant[26,27].

In spite of the difference in trial populations between the present study and previous work, the broad agreement on spinal posture between the present study and previous work in the literature provides confidence that the trends observed when loading increases beyond that of bodyweight alone are accurate. This study was also the first study to look at the effect of additional loading in standing postures which begins to be representative of the kind of spinal deformation changes that would be observed during activities of daily living. The increased loading during ADLs is likely therefore to result in further changes to spinal posture, such as increased lordosis, than those typically observed between the relaxed supine and standing positions. Due to the links between loading and posture with disc height loss and bulging it may be the case that patients who present pain during daily activity do not display mechanical symptoms such as disc protrusion and nerve impingement when undergoing medical imaging.

Conclusion

Axial loading in the standing position greater than bodyweight alone resulted in increased lordotic curvature of the lumbar spine through discs L1/L2 to L4/L5 in 10 asymptomatic male participants aged 22-32 years. Lordotic angle in the L5/S1 disc was reduced in the standing position relative to supine baselines but remained effectively unchanged by the addition of further loading in the standing position. A linear mixed models approach found loading position to be a significant factor ($F = 3.41$, $p < 0.05$) in lordotic angle between adjacent vertebral pairs however pelvic angle between the S1 vertebrae and the horizontal plane was not significantly changed by loading position ($P > 0.05$). Understanding these changes in spinal posture is key for clinicians using imaging to diagnose mechanical factors in back or leg pain, particularly if patients present pain during activity but suffer reduced or no pain when supine or at rest.

List of Funding Sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of Interest

The authors declare that there is no conflict of interest.

Ethics

Informed consent was obtained from all participants prior to testing and all work was approved by and conducted in accordance with guidelines set by the Manchester Metropolitan University Faculty of Science and Engineering ethics board.

References

[1] Bevan S. The Impact of Back Pain on Sickness Absence in Europe . University of Lancaster; 2012.

[2] Cassidy JD, Carroll LJ, Cote P. The Saskatchewan Health and Back Pain Survey: The Prevalence of Low Back Pain and Related Disability in Saskatchewan Adults. Spine (Phila Pa 1976) 1998;23:1860–6.

[3] Lidgren L. The bone and joint decade 2000-2010. Bull World Heal. Organ, vol. 81, Switzerland: 2003, p. 629.

[4] Dagenais S, Caro J, Haldeman S. A systematic review of low back pain cost of illness studies in the United States and internationally. Spine J 2008;8:8–20. doi:10.1016/j.spinee.2007.10.005.

[5] Omarker K, Myers RR. Pathogenesis of sciatic pain: role of herniated nucleus pulposus and deformation of spinal nerve root and dorsal root ganglion. Pain 1998;78:99–105. doi:http://dx.doi.org/10.1016/S0304-3959(98)00119-5.

[6] KOSTUIK J, HALL B. Spinal fusions to the sacrum in adults with scoliosis. Spine (Phila Pa 1976) 1983.

[7] Jackson R, McManus A. Radiographic Analysis of Sagittal Plane Alignment and Balance in Standing Volunteers and Patients with Low Back Pain Matched for Age, Sex, and Size: A. Spine (Phila Pa 1976) 1994.

[8] Keller T, Nathan M. Height change caused by creep in intervertebral discs: a sagittal plane model. J Spinal Disord Tech 1999.

[9] Komori H, Shinomiya K, Nakai O, Yamaura I, Takeda S. The natural history of herniated nucleus pulposus with radiculopathy. Spine (Phila Pa 1976) 1996.

[10] Gooyers CE, Callaghan JP. Exploring interactions between force, repetition and posture on intervertebral disc height loss and bulging in isolated porcine cervical functional spinal units from sub-acute-failure magnitudes of cyclic compressive loading. J Biomech 2015;48:3701–8. doi:10.1016/j.jbiomech.2015.08.023.

[11] Heuer F, Schmidt H, Wilke H-J. The relation between intervertebral disc bulging and annular fiber associated strains for simple and complex loading. J Biomech 2008;41:1086–94. doi:10.1016/j.jbiomech.2007.11.019.

[12] Wisneski RJ, Garfin SR, Rothman RH, Lutz GE. Lumbar disc disease. Spine (Phila Pa 1976) 1999;1:613–79.

[13] Hioki A, Miyamoto K, Sakai H, Shimizu K. Lumbar axial loading device alters lumbar sagittal alignment differently from upright standing position: a computed tomography study. Spine (Phila Pa 1976) 2010;35:995–1001. doi:10.1097/BRS.0b013e3181bb8188.

[14] Wisleder D, Smith MB, Mosher TJ, Zatsiorsky V. Lumbar spine mechanical response to axial compression load in vivo. Spine (Phila Pa 1976) 2001;26:E403–9.

[15] Danielson B, Willen J. Axially loaded CT and MRI of lumbar spine—a method to achieve an accurate radiological diagnosis in patients with low back pain. Adv. Spinal Fusion, New York: Marcel Dekker, Inc; 2003.

[16] Kimura S, Steinbach GC, Watenpaugh DE, Hargens AR. Lumbar spine disc height and curvature responses to an axial load generated by a compression device compatible with magnetic resonance imaging. Spine (Phila Pa 1976) 2001;26:2596–600.

[17] Wilke HJ, Neef P, Caimi M, Hoogland T, Claes LE. New In Vivo Measurements of Pressures in the Intervertebral Disc in Daily Life. Spine (Phila Pa 1976) 1999;24:755–62.

[18] Sato K, Kikuchi S, Yonezawa T. In Vivo Intradiscal Pressure Measurement in Healthy Individuals and in Patients with on going Back Problems. Spine (Phila Pa 1976) 1999;24:2468–74.

[19] Lisi AJ, O'Neill CW, Lindsey DP, Cooperstein R, Cooperstein E, Zucherman JF. Measurement of In Vivo Lumbar Intervertebral Disc Pressure During Spinal Manipulation: A Feasibility Study. J Appl Biomech 2006;22:234–9.

[20] Middleditch A, Oliver J. Functional Anatomy of the Spine. Second. London: Elsevier Butterworth Heinemann; 2005.

[21] Izambert O, Mitton D, Thourot M, Lavaste F. Dynamic stiffness and damping of human inter-vertebral disc using axial oscillatory displacement under af ree mass system. EurSpineJ 2003;12:562–6.

[22] Kingsley MI, D'Silva LA, Jennings C, Humphries B, Dalbo VJ, Scanlan AT. Moderate-intensity running causes intervertebral disc compression in young adults. Med Sci Sport Exerc 2012;44:2199–204. doi:10.1249/MSS.0b013e318260dbc1.

[23] Wood KB, Kos P, Schendel M, Persson K. Effect of patient position on the sagittal-plane profile of the thoracolumbar spine. J Spinal Disord 1996;9:165–9.

[24] Schmorl G, Junghanns H. The Human Spine in Health and Disease. Second Ame. New York: Grune and Stratton; 1971.

[25] Adams MA, Roughley PJ. What is Intervertebral Disc Degeneration, and What Causes It? Spine (Phila Pa 1976) 2006;31:2151–61.

[26] John C. Anthropometry for Designers. 2n D Ed ISBN 1980.

[27] Chengalur SN, Bernard TE, Rodgers SH. Kodak's ergonomic design for people at work. Wiley; 2004.