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The Relation Between Sacral Angle and Vertical Angle of Sacral Curvature and Lumbar Disc Degeneration

A Case–Control Study

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Abstract: The purpose of this study is to determine the reliability and validity of a goniometric measurement of the vertical angle of the sacrum and sacral angle (SA), and their relationships to lumbar degeneration.

A herniated lumbar disc is one of the most frequent medical issues. Investigators in a number of studies have reported associated risk factors for prevalent disc degeneration. Atypical lumbosacral angles and curvature are thought to contribute to the degradation of the spine by many researchers. This study analyzed 360 patients referred to our clinic from 2013 to 2015 due to low back pain. A cross-sectional case–control study was designed in order to compare the sagittal alignment of the lumbosacral area in 3 groups of patients suffering from LBP. A total 120 patients were in a control group with a normal lumbar magnetic resonance imaging (MRI), 120 patients had lumbar disk herniation (LDH), and 120 patients had spinal stenosis. From the sagittal plan of lumbar MRI, SA and vertical angle of sacral curvature (VASC) were determined and then analyzed.

The means of VASC in these groups were: 38.98 (SD: 6.36 ± 0.58), 40.89 (SD: 7.69 ± 0.69), and 40.54 (SD: 7.13 ± 0.92), respectively ($P = 0.089$). Moreover, studies of SA in 3 groups showed that the means of SA were: 39.30 (SD: 6.69 ± 0.63), 40.52 (SD: 7.47 ± 0.65), and 35.63 (SD: 6.07 ± 0.79), respectively. Relation between SA and spinal stenosis was just statistically significant ($P \leq 0.05$).

One significant limitation of our study is the lack of standing MRI for increased accuracy of measurement. However, we were reluctant to give patients needless exposure to radiation from conventional X-ray, and instead used MRI scans. We did not find any significant correlation between the VASC and LDH in lumbar MRI. Also, SA is not an independent risk factor for LDH in men and women. We suggested that there are several biomechanical factors involved in LDH.

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Abbreviations: LBP = low back pain, LDH = lumbar disc herniation, PI = pelvic incidence, SA = sacral angle, VASC = vertical angle of sacral curvature.

INTRODUCTION

Lumbar disc herniation (LDH) is one of the most frequent medical issues[1] and, for many years, lumbar discectomy has been one of the most common surgical procedures performed by neurosurgeons.[2] In the 1990s, the advent of magnetic resonance imaging (MRI) and the development of its modalities considerably contributed to the expansion of our knowledge of LDH.[3] Investigators in a number of studies have reported associated risk factors for prevalent disc herniation.

These risk factors include: body mass index (BMI), back pain, occupational exposures, and physical activity; however, the results are incongruous.[4–7] There was no obvious association with smoking, alcohol, and hormone therapy use. The other major limitation with current studies is that most people have some degree of radiologic abnormality in the spine, even at younger ages.[8,9] A herniated lumbar disc causes symptoms of sciatica, paraesthesia, numbness, or weakness. Lower back pain (LBP) is a particularly aggravating condition that is common, poorly understood, and difficult to manage. Atypical lumbosacral angles and curvatures are thought to contribute to spinal degradation by many researchers.[10] The normal orientation of lumbosacropelvic structure plays an important role in determining the shear and compressive forces applied on the anterior (vertebral body and intervertebral discs) and posterior (facet joints) elements of the lumbar vertebral column.[11] Therefore, the interest in morphologic analysis of lumbosacropelvic structure among the academic medical community is increasing.

The sacral angle (SA) is a straight line along the superior margin of the sacrum, drawn to meet the horizontal line[12] (Figure 1). We assumed that the mechanics of load transfer in the spine and in the intervertebral disc are important factors in understanding the patterns and mechanisms of disc pain and, in our study, the SA may be a risk factor for induced lumbosacral disc degenerations. Sacral curvature (SC), represented by the angle between the first and the last sacral vertebrae, is a feature that differentiates the human pelvis from that of other animals.[14–16] In some cases, the surface of the sacrum is nearly linear with slight curvature. In others, the curvature is over the entire length of the sacrum, particularly toward the middle. Other cases have less curvature, affecting only the lower third of the body.[17] It is unclear whether the degrees of vertical angles of sacral curvature are the same for all adult patients with disc herniation. Some authors analyzed this angle and compared the results in patients without any lumbar disc disease,[17] introducing the new risk factor. In our work experience, we felt that the angle of the sacral in some patients with degenerative lesions

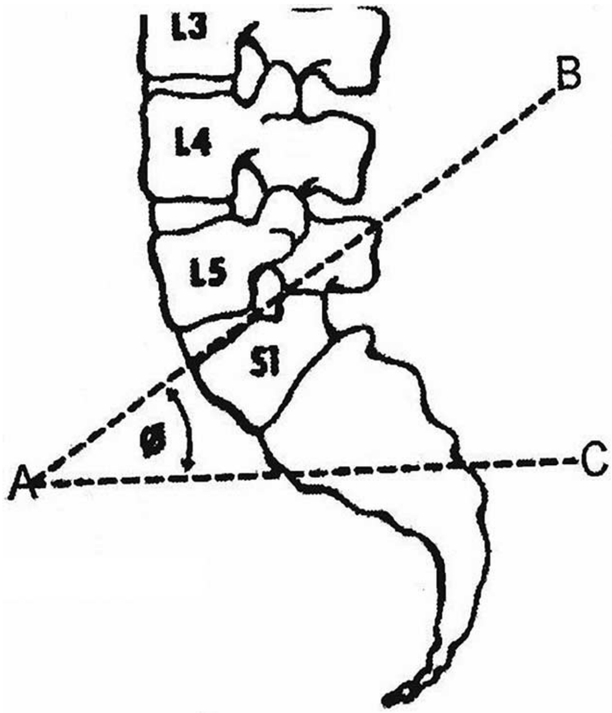

FIGURE 1. Sacral angle.[13]

FIGURE 2. SA and VASC measurements in a patient with normal T2 sagittal MRI. MRI = magnetic resonance imaging, SA = sacral angle, VASC = vertical angle of sacral curvature.

require surgery varied by ordinary people. We designed a prospective complementary study for verification of these studies, as well as the effect of SA in the process of back pain and lumbar degeneration that is presented here.

METHODS AND MATERIALS

A cross-sectional case–control study was designed to compare the sagittal alignment of the lumbosacral area in 3 groups of patients suffering from LBP. This study has been approved by the institutional review board of the Orthopedic Health Research of Mazandaran University of Medical Science in Iran. In this case report, written informed consent was obtained from the patient, and we had consent to use the accompanying images. This study analyzed 463 patients referred to our clinic from 2013 to 2015 due to LBP. After evaluation of this patients, we utilized 3 groups in our study. Among the 360 selected patients, 120 patients were in a control group with normal lumbar MRI, 120 patients had LDH, and 120 patients had spinal stenosis. To provide group homogeneity we made exclusion and inclusion criteria (Figure 2).

Two diagnostic criteria for spinal stenosis were used in this study. The first criterion was neurological claudication for at least 3 months with normal dorsalis pedis and tibialis posterior circulations. Second, MRI evidence was used for central spinal canal diameter of less than 9 mm. Criterion for the diagnosis of degenerative disc disease in the subjects was back pain with radiculopathy that was present for at least 3 months with evidence of degenerative disc disease and evidence of involvement on MRI. After completing a thorough history and determining demographic characteristics, diagnostic tests were performed. The control group had chronic LBP without imaging abnormality in MRI.

The exclusion criteria were as follows: BMI value of less than 20 or greater than 40, age younger than 20 and older than 70 years, previous surgery, associated lumbar spine fracture, spondylolisthesis, foraminal or extraforaminal disc herniation, spine tumors, infection, and bone methabolic diseases. The patients had received no drug treatment or exercise, for about 2 weeks before the MRI (such as nonsteroidal antiinflammatory drugs).

In the present study, both subjects and control groups were included if the VAS for pain was between 5 and 8; since the pain scale was roughly similar, the postural component would not be much different between the 2 groups. Also, patients with LDH may sometimes present a forward-bending posture when walking as the sagittal balance might have been affected by sciatic stimulation and tonic contraction of the surrounding lumbopelvic muscles.[18]

These patients were divided into 2 groups according to their sex. After giving informed consent, MRI was obtained as part of our routine center schedule. All patients underwent MRI acquisition on the same 1.5T system (Signa Excite, GE medical systems, Milwaukee, WI) using the spine coil to maximize the signals. From the T2 sagittal plan of the lumbar MRI, the angle between the first and the last sacral vertebrae (sacral curvature) and the vertical angle of sacral curvature were determined as the angle created between the intersection of a line running centrum of sacral curvature and a vertical line (Figures 3–5). A straight line along the superior margin of the sacrum was drawn to meet the horizontal line named the SA (Figures 3–5). We measured these values by geometrical construct. Two different radiologists independently reviewed and reported on the imaging. Only the reports that are consistent with each other were selected. Patient files and radiological data were reviewed. Data on age and sex, vertical angle of sacral curvature (VASC), were recorded.

Statistical Analysis

All values are expressed as the means ± SDs. Data were analyzed using the Statistical Package for the Social Sciences

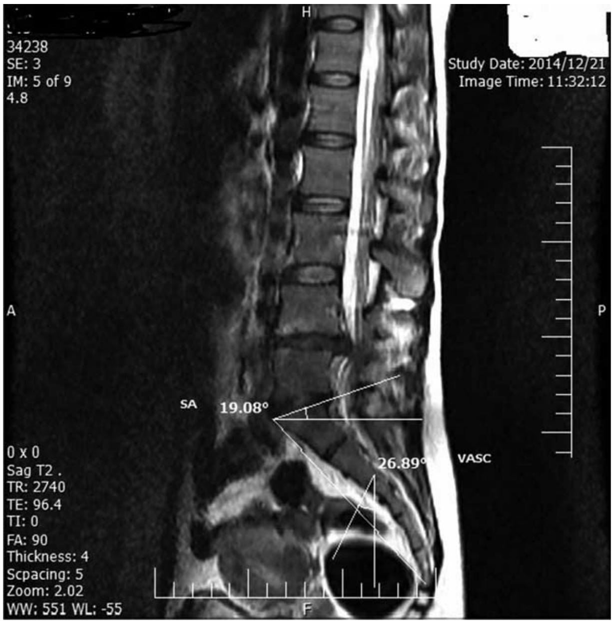

FIGURE 3. Sacral angle and vertical angle of sacral curvature measurements in a patient with lumbar disc herniation on T2 sagittal magnetic resonance imaging (MRI).

version (SPSS). The comparisons between parameters were performed using analysis of variance (ANOVA) test, Analytic *t*-test, Scheffe test, Chi-square test. Analytic *t*-test and a one-way ANOVA used for quantitative variables (angles), and Chi-square for qualitative variables (sex). Scheffe test used for multiple comparisons of parameters between groups. The level of significance was set at 0.05.

FIGURE 4. Sacral angle and vertical angle of sacral curvature measurements in a patient with spinal stenosis on T2 sagittal magnetic resonance imaging (MRI).

RESULTS

The mean age of the first control group comprised of 120 subjects was of 39.06 years. The second group, comprised of 120 patients with LDH cases had a mean age was of 46.17 years. The final group of 120 patients with spinal stenosis had a mean age was of 57.37 years. Age was significantly higher in patients with spinal stenosis ($P = 0.00$).

This article studied the VASC and SA in control, LDH, and spinal stenosis groups. The total means VASC in these groups were 38.98 (SD: 6.36 ± 0.58), 40.89 (SD: 7.69 ± 0.69), and 40.54 (SD: 7.13 ± 0.92), respectively ($P = 0.089$). Moreover, studies of SA in the 3 groups showed that the means of SA were 39.30 (SD: 6.69 ± 0.63), 40.52 (SD: 7.47 ± 0.65), and 35.63 (SD: 6.07 ± 0.79) in control, LDH, and spinal stenosis groups, respectively. Relation between SA and spinal stenosis was just statistically significant ($P \leq 0.05$).

The mean vertical angle of sacral curvature and SA according to sex in 3 groups can be seen in Table 1. There was no statically significant difference in male and female for either parameter (VASC: $P = 0.128$ vs SA: $P = 0.378$).

DISCUSSION

LBP is one of the most common causes of medical visits globally. The prevalence of LBP in adults has been recorded as high as 60% to 90%.[9] The association between changes in lumbar lordotic alignment and LBP is well delineated in literature.[19,20] There is a lot of parameter and angles in pelvic and lumbosucral which many studies are explain all of this on sagittal imbalance or degeneration in lumbosucral compliance with different conclusions most of them studied this measures on X-rays and did not used MRI. All pelvic parameter likes: pelvic incidence (PI), sagittal vertical axis, pelvic tilt (PT), and sacral slope could be measured better in X-ray rather than MRI and some of this parameter like PI need spesific hip and lombar X-rays together.

The angle of incidence is the algebraic sum of 2 paired angles: PT and sacral slope (SS). As the value of incidence is fixed for any given patient, the sum of PT and sacral slope is a persistent value: when one increases, the other necessarily decreases.[21]

RESULTS

The position of the lumbar spine, committed to the sacral plateau, is thus affected by the PT and by the sacral slope. Therefore, the pelvic parameters affect the entire underlying sagittal spinal profile.

However, previous studies mainly assessed sagittal imbalance and pelvic parameters in LBP or spondylolisthesis, while few of them are interested these issues of disc degeneration.[13,21–38] Because discogenic pain is one of the important causes of LBP,[24] evaluating its associated factors, such as alteration in lumbar lordosis and sacral parameters, seems invaluable. Most studies on lumbosacral morphology have been conducted on populations with LBP[25,26] or on isthmic spondylolisthesis,[27,28] but the number of studies on individuals with intervertebral disc degeneration or disc herniation is considerably low.[13] The normal orientation of lumbosacropelvic building plays an important role in the specification of shear and compressive forces applied on the anterior (intervertebral discs and corpus vertebrae) and posterior (facet joints) structures of lumbarvertebral column.[29] The sacrum of humans is not positioned posteriorly at birth and it is during the first few years that the sacrum moves dorsally in relation with the progressive

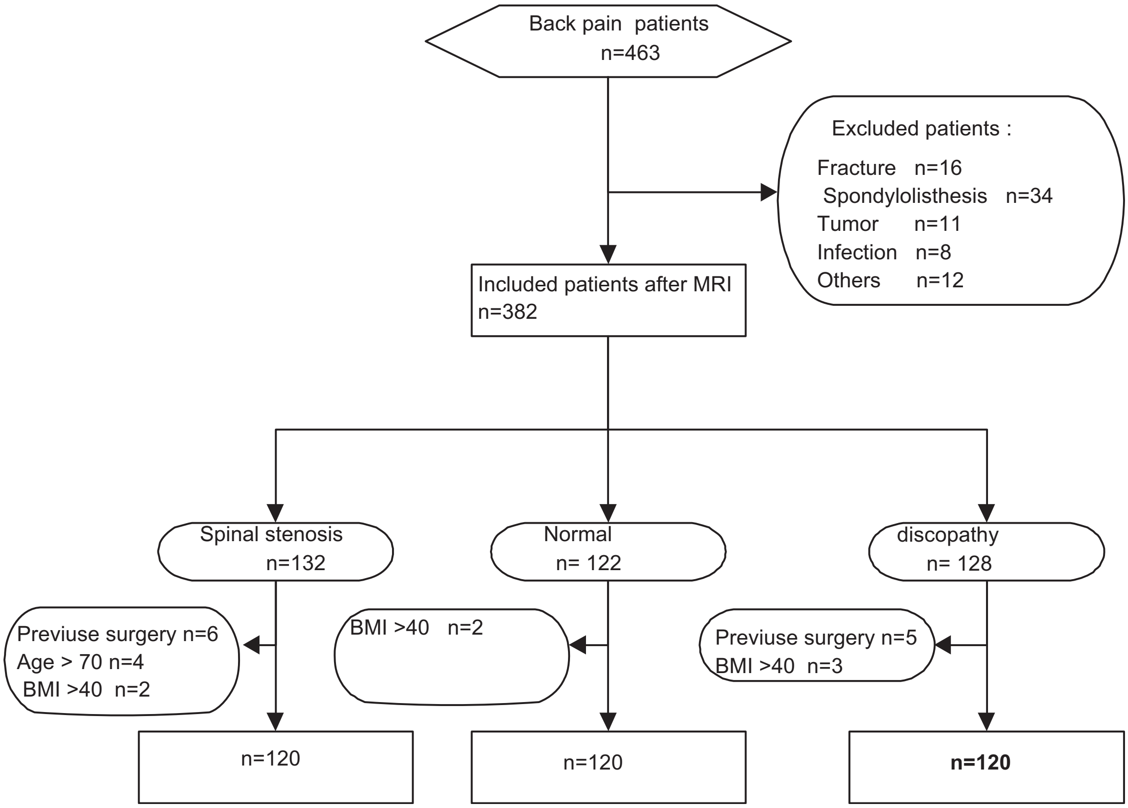

FIGURE 5. Flow chart that shows the patient selection process.

attainment of erect posture and the ontogeny of bipedal propulsion. Due to the erect position, the pelvic bone structure is subjected to new static and dynamic relations, which play an important role in describing the formation of this region.[3,30,31]

The weight borne by the cervical and thoracic vertebrae is loaded to the lumbosacral spine. The lumbosacral joint also permits flexion, extension, and rotation movements. It is therefore subject to subluxation and frequent injuries and important in the assessment of back pain and in traumatic medicine.[32]

The SA is defined as the angle formed between the superior surface of the sacrum and the horizontal line[33] (Figure 1); the lumbosacral angle has been associated with instability and LBP in the final 3 to 6 decades of life. Therefore, knowledge of the range of normal lumbosacral angles is critical in the treatment of LBP.[34]

Thus, the changes in sagittal alignment may lead to changes in the lumbar spine kinematics, which will subsequently influence load bearing and the occurrence of disc degeneration.[35]

TABLE 1. Show the Mean Vertical Angle of Sacral Curvature and Sacral Angle for Male and Female in the 3 Groups

	Number	Bulging	Protrusion	Extrude	Mean Age, year	Mean SA ± SD	Mean VASC ± SD
Female normal group	86	–	–	–	39.8	39.21 ± 6.38	39.03 ± 7.13
Male normal group	34	–	–	–	41.1	39.53 ± 6.41	38.87 ± 6.60
Total (normal group)	110	–	–	–	39.06	39.30 ± 6.69	38.98 ± 6.36
Female with LDH	80	12	52	16	45.22	41.27 ± 7.65	42.05 ± 6.94
Male with LDH	40	3	22	15	46.44	38.85 ± 7.60	38.31 ± 8.03
Total (LDH group)	110	15	74	31	46.17	40.52 ± 7.47	40.89 ± 7.69
Female with spinal stenosis	69	19	–	–	56.45	35.87 ± 7.63	40.62 ± 6.60
Male with spinal stenosis	51	11	–	–	58.32	35.15 ± 6.22	40.40 ± 5.08
Total (stenosis group)	110	30	–	–	57.37	35.63 ± 6.07*	40.54 ± 7.13
Total	360	45	74	31	45.57	39.11 ± 7.29	40.09 ± 7.06

LDH = lumbar disc herniation, SD = standard deviation, VASC = vertical angle of sacral curvature.
* $P < 0.05$ relation between sacral angle and spinal stenosis.

Our study is not a review of articles, but we pay serious attention to the results of other studies in the field of communication between lumbosacral sagittal alignment and disc degeneration. Khodair et al[13] evaluated the relationship between lumbosacral morphological parameters and intervertebral disc degenerative disease. They showed that there was no statistically significant difference between normal population and patients with disc pathology in regards to the lumbar lordosis angle ($P > 0.05$), while a statistically significant difference was observed in regards to both sacral kyphosis angle and sacral table angle. In addition, Ergun et al[10] investigated the relation between various morphological parameters (sacral table angle and sacral kyphosis) and LDH or degeneration. They showed a statistically significant difference with regard to the angles of lumbar lordosis, sacral kyphosis, and sacral table, which was determined between individuals with and without intervertebral disc herniation ($P = 0.001$, 0.0001, 0.0001, respectively).

A cross-sectional case–control study was designed by Habibi et al[36] in 2014 in order to evaluate the correlation between lumbosacral sagittal alignment and disc degeneration. They showed that the proposed global lumbosacral angle in the subject group was less than the control group, with the difference being statistically significant ($P = 0.002$). However, lumbar lordosis based on Cobb's method was lower in the group with discopathy than the control group, although it was not statistically significant. In 2012, Kanat et al[17] introduced a new risk factor for LDH in females of an area of Turkey in order to characterize the importance of the vertical angle of the sacral curvature (VASC) in LDH. They have derived morphological data from lumbar sagittal MRI. The statistical significance of the findings is discussed. The angles of 60 female patients with LDH were compared with the 34 female patients without LDH. The vertical angle of sacral curvature is statistically significantly bigger in females with LDH, when compared to subjects in the control group, 28.32 and 25.4, respectively. ($P = 0.034$). The same difference was not seen in males.[17] In the current study, we focused on 2 angles of sacral morphology on the sagittal MRI of patients referred due to LBP in our spine clinic. Our experience shows us the changes in the morphology of the sacrum and lumbar degenerative disorders observed in patients with sagittal view of MRI and, in particular, found that the SA could be significantly changed in patients with discopathy who need to surgery. Accordingly, we decided that there was a need for a prospective cross-sectional study comparing these 2 angles (VASC and SA) in patients with LBP. We studied 360 patients over a certain period so that there were more subjects than Kanat study. In addition, patients with lumbar stenosis were also entered to our study.

Although the number of women in the study in all 3 groups was almost more than 2 times more than the men's group, (unlike the Kanat et al study, wherein the majority of patients were female), significant independent influence of each of the angles on a particular sex was not found. Moreover, a significant relationship between these 2 angles and LDH groups compared with the normal group was not found, but SA in spinal stenosis group had a significant relationship compared to the other 2 groups. However, the mean age of stenosis group was higher than other 2 groups; spinal stenosis occurs at an older age than LDH. The SA has also been associated with some degree of instability and LBP in the last 3 to 6 decades of life. Thus, aging may affect SA changes in the stenosis group.

Different factors contributing to the creation of the vertical angle of sacral curvature. The consequence of erect posture tilts the upper part of the sacrum dorsally and the lower portion of the sacrum ventrally, and the impact of supine posture affects the progress of the lower portion of the sacrum.[37] In addition to supine posture, the levator ani, which is well established in homo sapiens, also disturbs the lower part of the sacrum and coccyx, and influences its ventral alignment. Variations of the VASC can be a consequence of differences in onset and incidence of supine posture. It was greater in conventional X-rays than MRI.[37] On the other hand, some lumbopelvic measures, like PI, are persistent, as everyone knows. However, PI might have variation mutually because of increased shear force on the sacroiliac joint and subsequent surgical modification of fixed lumbar lordosis (LL).[38] Thus, the spinopelvic parameters should be engaged from the standing graphics, and one limitation of our study is the lack of standing MRI for increased accuracy of measurement. However, we were reluctant to expose patients to needless radiation from conventional X-rays, and instead used MRI scanners. The problem, here, may be important with regard to the parameters, which are calculated on MRI in the lying position and then referenced with a vertical line. This reference line may not resemble the standing position. This should not be problematic as the sacral curve is the factual part of the spinal curves. However, further studies will solve these problems by means of standing MRI.

The purpose of this study is to determine the reliability and validity of a goniometric measurement of the vertical angle of sacrum and SA. We found no statistically significant difference between men and women with LDH (and without intervertebral disc disease) and there is no significant relationship between a patient's age and their sacral parameters. In contrast with Kanat et al, we did not find any significant relationship between VASC and LDH in both men and women via MRI. We do not agree with our colleagues that the VASC could be an important risk factor in the development of disc degeneration and back problems.

It seems conditions contributing to lumbar disc degeneration are multifactorial and changes in morphology and angles in the lumbosacropelvic area can affect the biomechanics of spinal structures leading to discopathy and degeneration maybe, a specific factor alone cannot be responsible for all of the above. In addition, differences in the biomechanics of the angles formed by the structures in this area in different races and daily activities can affect the resulting pathology. Thus, certain factors in women or men alone can be associated with the dissatisfaction of patients after lumbar disc surgery.

Due to our results of spinal stenosis, and probably different underlying factors in the creation of spinal degeneration, SA cannot be an independent and decisive factor for the etiology of spinal stenosis until further supplementary studies are conducted.

Like most studies, not using standing MRI is the significant limitation of our study another limitations are the small numbers of samples and inequality between the sexes. It seems attention more to other factors like, race, duration of symptoms, MRI features, degree of stenosis, levels of disc bulges, comorbidities, family history, social factors, and environmental/physical exposures could increase the value of the results and can be a target for future studies.

CONCLUSIONS

We did not find any significant correlation between vertical angle of sacral curvature and LDH in lumbosucral MRI. Also, SA is not an independent risk factor for LDH in men and women. However, we continue to stress that there are several biomechanical factors involved in LDH.

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REFERENCES

1. Naderi S, Egemen N, Gokalp H, et al. The value of dermatomal somatosensory-evoked potential in evaluation of herniated lumbar disc. *Turk Neurosurg.* 1992;2:139–143.
2. Sasani M, Oktenoğlu T, Tuncay K, et al. Total disc replacement in the treatment of lumbar discogenic pain with disc herniation: a prospective clinical study. *Turk Neurosurg.* 2009;19:127–134.
3. Choi KC, Kim JS, Jung B, et al. Dynamic lumbar spinal stenosis: the parameters and pain. *Eur Spine J.* 2000;9:47–55.
4. Yoshimura N, Dennison E, Wilman C, et al. Epidemiology of chronic disc degeneration and osteoarthritis of the lumbar spine in Britain and Japan: a comparative study. *J Rheumatol.* 2000;27:429–433.
5. O'Neill TW, McCloskey EV, Kanis John A, et al. The distribution, determinants, and clinical correlates of vertebral osteophytosis: a population based survey. *J Rheumatol.* 1999;26:842–848.
6. Frymoyer JW, Newberg A, Pope MH, et al. Spine radiographs in patients with low-back pain: an epidemiological study in men. *J Bone Joint Surg Am.* 1984;66:1048–1055.
7. Torgerson WR, Dotter WE. Comparative roentgenographic study of the asymptomatic and symptomatic lumbar spine. *J Bone Joint Surg Am.* 1976;58:850–853.
8. Lane NE, Michel B, Bjorkengren A, et al. The risk of osteoarthritis with running and aging: a 5-year longitudinal study. *J Rheumatol.* 1993;20:461–468.
9. Symmons DPM, van Hemert AM, Vandenbroucke JP, et al. A longitudinal study of back pain and radiological changes in the lumbar spines of middle aged women. II. Radiographic findings. *Ann Rheum Dis.* 1991;50:162–166.
10. Ergun T, Lakadamyali H, Sukru Sahin M. The relation between sagittal morphology of the lumbosacral spine and the degree of lumbar intervertebral disc degeneration. *Acta Orthop Traumatol Turc.* 2010;44:293–299.
11. Roaf R. Vertebral growth and its mechanical control. *J Bone Joint Surg Br.* 1960;42-B:40–59.
12. Dubousset J. Treatment of spondylolisthesis and spondylolysis in children and adolescents. *Clin Orthop.* 1997;37:77–85.
13. Khodair SA, Ghieda UE, Eltomey MA. Relationship of lumbosacral spine morphometrics and lumbar disc degenerative disease in young adults using magnetic resonance imaging. *Egypt J Radiol Nucl Med.* 2014;45:461–466.
14. Cosan TE, Adapinar B, Aslantas A, et al. Is lumbar spinal reserve capacity on CT-myelography significant? *Turk Neurosurg.* 1998;8:114–118.
15. Legaye J, Duval-Beaupère G, Hecquet J, et al. Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. *Eur Spine J.* 1998;7:99–103.
16. Wiltse LL, Winter RB. Terminology and measurement of spondylolisthesis. *J Bone Joint Surg Am.* 1983;65:768–772.
17. Kanat A, Yazar U, Kazdal H, et al. Introducing a new risk factor for lumbar disc herniation in females: vertical angle of the sacral curvature. *J Korean Neurosurg Soc.* 2012;52:447–451.
18. Endo K, Suzuki H, Tanaka H, et al. Sagittal spinal alignment in patients with lumbar disc herniation. *Eur Spine J.* 2010;19:435–438.
19. Evcik D, Yucel A. Lumbar lordosis in acute and chronic low back pain patients. *Rheumatol Int.* 2003;23:163–165.
20. Youdas JW, Garrett TR, Egan KS, et al. Lumbar lordosis and pelvic inclination in adults with chronic low back pain. *Phys Ther.* 2000;80:261–275.
21. Le Huec JC, Aunoble S, Leijssen P, et al. Pelvic parameters: origin and significance. *Eur Spine J.* 2011;20(Suppl 5):S564–S571DOI 10.1007/s00586-011-1940-1).
22. Barrey C, Jund J, Noseda O, et al. Sagittal balance of the pelvis-spine complex and lumbar degenerative diseases. A comparative study about 85 cases. *Eur Spine J.* 2007;16:1459–1467.
23. Endo K, Suzuki H, Tanaka H, et al. Sagittal spinal alignment in patients with lumbar disc herniation. *Eur Spine J.* 2010;19:435–438.
24. Salminen JJ, Erkintalo MO, Pentti J, et al. Recurrent low back pain and early disc degeneration in the young. *Spine (Phila Pa 1976).* 1999;24:1316–1321.
25. Vialle R, Levassor N, Rillardon L, et al. Radiographic analysis of the sagittal alignment and balance of the spine in asymptomatic subjects. *J Bone Joint Surg Am.* 2005;87:260–267.
26. Miyazaki M, Hymanson HJ, Morishita Y, et al. Kinematic analysis of the relationship between sagittal alignment and disc degeneration in the cervical spine. *Spine (Phila Pa 1976).* 2008;33:E870–E876.
27. Andreasen ML, Langhoff L, Jensen TS, et al. Reproduction of the lumbar lordosis: a comparison of standing radiographs versus supine magnetic resonance imaging obtained with straightened lower extremities. *J Manipulative Physiol Ther.* 2007;30:26–30.
28. O'Connell GD, Johannessen W, Vresilovic EJ, et al. Human internal disc strains in axial compression measured noninvasively using magnetic resonance imaging. *Spine (Phila Pa 1976).* 2007;32:2860–2868.
29. Roaf R. Vertebral growth and its mechanical control. *J Bone Joint Surg Br.* 1960;42-B:40–59.
30. Gregory WK. The upright posture of man: a review of its origin and evolution. *Proc Am Phylos Soc.* 1928;67:339–377.
31. Keith A. Men's posture: its evolution and disorders: Theories concerning the evolution of men's posture. *Br Med J.* 1923;1:451–455.
32. Abitbol MM. Evolution of the lumbosacral angle. *Am J Phys Anthropol.* 1987;72:361–372.
33. Meshan I. Farra-Meshan RM. (eds.) *Atlas of Normal Radiographic Anatomy*. (2nd edn.). Philadelphia: Saunders Company; 1985; 416–9p.
34. Ghormley RK. Etiologic study of back pain. *Pennsylvania Med J.* 1954;57:143–147.
35. Keorochana G, Taghavi CE, Lee KB, et al. Effect of sagittal alignment on kinematic changes and degree of disc degeneration in the lumbar spine: an analysis using positional MRI. *Spine (Phila Pa 1976).* 2011;36:893–898.
36. Habibi Z, Maleki F, Tayebi Meybodi A, et al. Lumbosacral sagittal alignment in association to intervertebral disc diseases. *Asian Spine J.* 2014;8:813–819.
37. Abitbol MM. Sacral curvature and supine posture. *Am J Phys Anthropol.* 1989;80:379–389.
38. Lee JH, Na KH, Kim JH, et al. Is pelvic incidence a constant, as everyone knows? Changes of pelvic incidence in surgically corrected adult sagittal deformity. *Eur Spine J.* 2015PMID: 26289634.