Correction of Grade 2 Spondylolisthesis Following a Non-Surgical Structural Spinal Rehabilitation Protocol Using Lumbar Traction: A Case Study and Selective Review of Literature

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ABSTRACT

Objective: Discuss the use of non-surgical spinal rehabilitation protocol in the case of a 69-year-old female with a grade 2 spondylolisthesis. A selective literature review and discussion are provided. Clinical Features: A 69-year-old female presented with moderate low back pain (7/10 pain) and severe leg cramping (7/10 pain). Initial lateral lumbar x-ray revealed a grade 2 spondylolisthesis at L4-L5 measuring 13.3 mm. Interventions and Outcomes: The patient completed 60 sessions of Mirror Image® spinal exercises, adjustments, and traction over 45 weeks. Post-treatment lateral lumbar x-ray showed a decrease in translation of L4-L5 from 13.3 mm to 2.4 mm, within normal limits. Conclusions: This case provides the first documented evidence of a non-surgical or chiropractic treatment, specifically Chiropractic BioPhysics®, protocols of lumbar spondylolisthesis where spinal alignment was corrected. Additional research is needed to investigate the clinical implications and treatment methods.

CASE REPORT

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Patient Presentation

A 5’7”, 160 lbs., 69-year old retired female presented with moderate low back pain (LBP) that she rated 7/10 on a scale where 0 is no pain and 10 is maximum pain. The patient also presented with severe cramping in her legs (7/10 pain) and that she requires custom bracing for chronic right knee issues. The patient reported seeing a physical therapist (PT) previously for these issues. The patient reported the use of pharmaceuticals to help relieve her symptoms. She stated that she was taking Baclofen, a muscle relaxer and antispasmatic agent, to alleviate her leg pain. She stated that she was taking magnesium, potassium, and glucosamine supplements to help address her leg cramps.

Radiographic Analysis

Radiographic analysis is an evidence-based, valid way to assess spinal alignment, subluxation, and postural abnormalities. Spinal radiographs are taken with the patient in a normal, neutral, upright, weight-bearing position. Spinal alignment abnormalities are “rotations and translations of the head, rib cage, and pelvis from a normal position in a 3-dimensional coordinate system.”[1] Spinal radiographs are used to analyze spinal structure to quantify spinal alignment and determine a specific approach to structural rehabilitation based on abnormal spinal alignment and vertebral subluxations.

The patient's radiographs were analyzed using the Harrison Posterior Tangent Method. The Harrison Posterior Tangent method is a valid and reliable x-ray line drawing method[2-12] in accordance with the Harrison Spinal Model, which is a valid geometric spinal model.[13-20] Lateral lumbar (LL) x-rays provide measurements of regional and intersegmental lumbar angles and regional and intersegmental lumbar translations. Lumbar angles are measured by drawing a line tangent to the posterior aspect of each vertebral body from L1 to L5. Measurements, from one vertebral body to the next, determine the relative rotational angle (RRA), while measurements of a spinal region provide the absolute rotation angle (ARA). Global anterior-to-posterior (AP) translations of the spine can be measured by drawing a vertical line from an inferior landmark and measuring the distance to a superior landmark perpendicular to the vertical line. AP translation of the lumbar spinal region is measured using the posterior, inferior body of the first sacral vertebra (S1) as the inferior landmark and the posterior, superior body of the twelfth thoracic vertebra (T12) as the superior landmark. Intersegmental AP translations are determined by measuring the distance to the superior vertebra perpendicular to the posterior tangent line of the vertebra below. All measurements and lines of mensuration are compared to evidence-based, valid, normal, ideal values.

A spinal radiographic analysis involved the Cartesian coordinate system to "describe translations and rotations of the head, thorax, and pelvis around x, y, and z-axes, in the coronal, sagittal, and transverse planes."[18] A shorthand method was used for documenting abnormal spinal alignment. In these spinal listings, the positive or negative sign indicates the direction of translation in or rotation around the x, y, and z-axes in the frontal, sagittal, and horizontal plane, respectively. The first letter denotes translation (T) or rotation (R). The second letter denotes the axis per the Cartesian coordinate system in or around which the T or R takes place. The third letter denotes the body region (head is H, thoracic cage is T, and pelvis is P) with respect to the body region below. As such, the head would be assessed with respect to the body region below (thoracic cage). The thoracic cage would be assessed with respect to the pelvis and the pelvis is assessed with respect to the feet. Following the 3-letter spinal listing which indicates the abnormal alignment, there is a reference to vertebral body landmarks to denote the anatomy involved.

The pre-treatment LL x-ray (Figure 1) revealed anterior translation of L4-L5 measuring 13.3 mm (ideal is 0 mm) (Table 1). The L4-L5 intersegmental translation was a grade 2 spondylolisthesis, was not within normal levels, and exhibited instability. RRA L5-S1 measured -14.8° (ideal is -33.0°), the sacral base angle (SBA) measured 29.4° (ideal is 40.0°) and the translation of L1-S1 measured 29.3 mm (ideal is 0 mm) (Table 1). X-ray analysis was done using computer-aided x-ray digitization using the Harrison Posterior Tangent Method according to the Harrison Spinal Model to provide spinal mensuration and comparison analyses.

Treatment

The patient completed 60 sessions of Mirror Image® spinal exercises, adjustments, and traction over 45 weeks. Mirror Image® structural rehabilitation of the spine aims to normalize spinal alignment and posture.[3] Per Mirror Image® protocols, the patient moves or is placed in the overcorrected, opposite postural position as presented using the Harrison Spinal Model for normal, healthy spinal alignment values.[13-20] From a normal spinal model, delineations from normal can be assessed for severity and used in determining necessity and approximate length of care.[3]

Mirror Image® Exercises

Mirror Image® exercises strengthen weak musculature and lengthen tight musculature that have adapted to unhealthy posture to correct and maintain corrections in spinal alignment and postural abnormalities.[1] Exercises consist of a contraction and relaxation cycle.

The patient was trained how to execute the exercises and monitored during the exercises. Exercises consisted of –TzT. The patient performed -TzT exercises by standing with their back facing a wall and placing a 7-inch foam block between the wall and the patient's buttocks and posteriorly translating their thoracic cage. The patient was instructed to contract in the Mirror Image® position for 3 to 4 seconds and then relax for 1 to 2 seconds for a total of 5 to 10 minutes.

Mirror Image® Adjustments

Mirror Image® adjustments were delivered to the patient using an OMNI elevation table with sectional drop-mechanisms. Drop table adjustments are used in order to stimulate mechanoreceptors and proprioceptors,[21] which are responsible for relaying the position of the body to the brain so that the brain knows the body's position in space.[22] The purpose of stimulating these sensory receptors during adjustments while in Mirror Image® position is to retrain the patient's central nervous system (CNS) to adapt to normal posture according to the Harrison Spinal Model.[21]

The patient was adjusted supine with –TzT to correct the +TzT. The pelvis was elevated to force the thoracic cage into a posterior position, and the patient's knees were passively brought their chest. Adjustments were applied by applying a downward force over the lumbars using the lumbar drop mechanism.

Mirror Image® Traction

Mirror Image® traction causes viscoelastic deformation of the ligaments of the spine to an overcorrected position. [1] The purpose of Mirror Image® traction is to reverse the patient's abnormal posture to normal by stressing relaxation of the ligaments, tendons, and muscles and initiating muscle creep therefore creating permanent restorative change.[21]

The patient received lumbar traction using the Total Target Force Counterstress Traction Unit (Total Target Force Counterstress Traction Unit, Promote Chiropractic, Inc., Saugus, MA, USA). The patient was positioned supine on a standard therapy table while the Target Force elevated the pelvis with a posterior-to-anterior (PA) force applied at S1-S2 with an AP force applied at L4-L3 in order to correct the spondylolisthesis. The purpose is to provide long-duration deformation forces to the soft tissues that have habituated to a patient's abnormal posture.[23] The typical patient starts with traction to their tolerance for 2 to 4 minutes and increases by 2 minutes with each visit until 15 to 20 minutes is achieved. In this case, the patient started with 4 minutes of traction and gradually progressed each visit to reach the desired 15-minute traction session.

Re-Exam 1 Findings

After 30 sessions over 11 weeks, a LL x-ray (Figure 2) was taken and compared with the pre-treatment assessment (Table 1). The re-exam 1 LL x-ray revealed that the L4-L5 spondylolisthesis was reduced 6.2 mm from 13.3 mm to 7.1 mm of anterior translation from pre-treatment. The L4-L5 intersegmental translation was a grade 1 spondylolisthesis, was not within normal levels, and exhibited instability. Translation of L1-S1 improved 4.2 mm from 29.3 mm to 25.1 mm and SBA improved 4.8° from 28.9° to 33.7° from pre-treatment to re-exam 1.

Re-Exam 2 Findings

After 60 sessions over 45 weeks, a LL x-ray (Figure 3) was taken and compared with the re-exam 1 assessment (Table 2) and the pre-treatment assessment (Table 3). The re-exam 2 LL x-ray revealed that the L4-L5 spondylolisthesis was reduced 4.7 mm from 7.1 mm to 2.4 mm of anterior translation from re-exam 1 and a total of 10.9 mm from 13.3 mm to 2.4 mm of anterior translation from pre-treatment. The L4-L5 intersegmental translation was within normal levels. RRA L5-S1 improved 3.2° from -15.6° to -18.8° and the sacral base angle improved 3.5° from 33.5° to 37.0° from re-exam 1 to re-exam 2. RRA L5-S1 improved a total of 4.0° from -14.8° to -18.8°, the translation of L1-S1 improved a total of 6.0 mm from 29.3 mm to 23.3 mm, and the SBA improved a total of 7.6° from 29.4° to 37.0° from pre-treatment to re-exam 2.

DISCUSSION

Etiology and Demographics

Spondylolisthesis is described as a translation of a vertebra with respect to the vertebra below without any modification or notable lesion to the pars interarticularis [24]. Abnormal weight distribution combined with soft tissue laxity and instability over a prolonged period allows for excessive joint play and buckling of the posterior annular fibers of the intervertebral disc (IVD).

A spondylolisthesis is an example of a vertebral subluxation as defined by the chiropractic profession. "Common to all concepts or definitions of [vertebral] subluxation are some form of kinesiologic dysfunction and some form of neurological involvement."[25] This includes one or more structural displacements of the spine and posture as rotation or translation away from normal spinal alignment in any of the three anatomical planes accompanied by pain or abnormal neurologic function.

Research suggests that anywhere from 6-31% of the United States population suffers from degenerative spondylolisthesis. [26-28] The most common level for degenerative anterolisthesis is L4-L5.[26,27] Females are 5 times more likely to suffer from anterolisthesis than males.[28,29] Changes in estrogen production and their effect on soft tissue have been suggested as a predisposing factor.[30] Other studies suggest that increased age, increased facet sagittalization, lumbar hypolordosis, increased body mass index (BMI) in females, and past pregnancies all could play a role in predisposition.[26,29,30] Kalichman, et. al described a significant relationship between degenerative spondylolisthesis and increased age (p=<0.0001). The study showed an increase in prevalence of degenerative spondylolisthesis from the age range of 50 to 90 years.[29] "By decade, degenerative spondylolisthesis was present in 0% of <40-years-olds; 2.1% of 40–49-years-olds, 10.8% of 50–59-years-olds, 41.7% of 60–69-years-olds, and 16.7% of ≥70-years-olds. The differences between age groups were highly significant, p=<0.0001 in total sample."[27]

Clinical and Imaging Findings

Abnormal spinal alignment and posture are associated with poor general health, physical function, emotional function, social function, and LBP.[31] Normal curves in sagittal spinal alignment provide shock absorption and leverage, which protect the spinal cord and nerve tissue from the forces of gravity and other daily traumas one may encounter.[32] Abnormal sagittal spinal alignment is shown to lead to an increase of injuries and falls in men and women over the age of 55 years.[33,34] Additional research indicated that abnormal spinal alignment and positional loading of the lumbar spine cause compressive, tensile, and shearing loads being applied to the abnormal curve.[35-38] Abnormal spinal alignment may lead to the development and progression of intersegmental translations. Spondylolisthesis has a significant correlation with spinopelvic sagittal alignment factors including spinal fusion,[39] anterior translation of the C7 plumb line,[40-43] thoracic hypokyphosis,[44-47] lumbar hypolordosis,[40,48,49] lumbar hyperlordosis,[41,42,44,46,47,50,51] anterior translation of the lumbar spine,[40,48] posterior translation of the lumbar spine,[50] increased angle of pelvic incidence,[40,43-45,47-49,51-53] increased pelvic tilt,[41,42,44,45,47] increased SBA,[42,44,45,47] and decreased SBA.[40,41,46,48] It is clear that sagittal spinopelvic balance has a significant impact on the development and the progression of spondylolisthesis. The patient in this case presented with a L4-L5 anterior translation of 13.3 mm (ideal is 0.0 mm), a translation of L1-S1 of 29.3 mm (ideal is 0 mm), and a SBA of 29.4 (ideal is 40.0°). The anterior translation at L4-L5 was corrected to 2.4 mm (82.0% improvement), the translation of L1-S1 was corrected to 23.3 mm (20.5% improvement), and SBA was corrected to 37.0° (25.9% improvement). The L4-L5 anterolisthesis was reduced as SBA was corrected. These results are consistent with the literature. [40,41,46,48]

Abnormal spinal alignment and posture also increase stress and strain to the neural tissues and vascular supply of the spinal cord. This can affect the body's sensory, motor, and autonomic nervous systems. It is a rare phenomenon for resolution of postural abnormalities in the absence of intervention.[54] However, there is literature that supports the effectiveness of structural spinal rehabilitation to restore a healthy spinal alignment and posture according to established, evidence-based normal values, thereby lowering the risk of degeneration.[55-61]

Treatment and Prognosis

More than 300,000 lumbar spinal fusions are performed in the United States each year and the number is increasing. Many of these fusions are performed to stabilize a spondylolisthesis [62]. Toteson, et. al examined the cost-effectiveness of surgical treatment for degenerative spondylolisthesis. Treatment effectiveness was measured using quality-adjusted life years (QALY). QALYs account for both length and quality of life by factoring time spent in each health state. The study found that cost per QALY gained for surgery compared to non-operative care was highest among those with degenerative spondylolisthesis ($64,300).[63]

Ong, et. al examined costs associated with 1,672 elderly patients who received posterior spine fusions (PSF). The study showed the rate of reoperation at 3 months, 1 year, and 2 years before initial surgery were 19.9%, 24.0%, and 28.0%, respectively.[64]

Non-operative treatment for degenerative spondylolisthesis remains widely underrepresented in the literature. Non-surgical methods in scientific literature include active physical therapy, education or counseling for exercising, nonsteroidal anti-inflammatory drugs (NSAIDs), homeopathic remedies, soft tissue massage, trigger point therapy, spinal mobilization techniques to restricted areas, cryotherapy, and chiropractic. [65-69] Weinstein reported that patients with image-confirmed degenerative spondylolisthesis and symptoms persisting for at least 12 weeks, the intention-to-treat analysis found no significant advantage to surgery over non-surgical care. The patients receiving non-surgical treatment, on average, showed moderate improvement in all outcomes.[65] However, in studies regarding non-surgical treatment of spondylolisthesis, patient improvement has been determined by outcome assessment tools including health-related quality of life (HRQOL) and pain measures[65,66] or by functional parameters including orthopedic assessment(s), palpation, disability indexes, muscle grading, strength assessment, activities of daily living (ADL) impairment, muscle atrophy, gait, neurological and sensory testing, and range of motion.[67-69] A search was conducted for the purposes of this case study using the search terms spondylolisthesis AND chiropractic OR non-surgical treatment OR non-surgical correction. The search yielded 31, 12, and 1 results in PubMed; 380, 190, and 41 in ScienceDirect; 129, 8, and 1 in Alt HealthWatch; 31, 12, and 1 in MEDLINE; and 18, 9, and 1 in Index to Chiropractic Literature research databases, respectively. Articles were filtered by those written or translated in English and those that included reduction in or correction of spinal misalignment associated with spondylolisthesis. There are 0 articles found that meet this inclusion criteria in any of the searched research databases. This case study is the first documented non-surgical or chiropractic treatment, specifically Chiropractic BioPhysics®, that resulted in correction of spinal alignment and improvement of spondylolisthesis associated symptomatology.

Differential Diagnosis

The differential diagnosis for degenerative spondylolisthesis includes lumbar compression fracture, lumbar canal stenosis, lumbar disc herniation, lumbar spondylolysis, and lumbar facet arthropathy.[70] These conditions often present with the similar clinical symptoms, such as LBP and radiculopathy. However, spondylolisthesis is often made worse with extension and is asymptomatic in many cases.[70]

In 2016, Matz, et. al provided an evidence-based clinical guideline for the diagnosis and treatment of degenerative lumbar spondylolisthesis. The guideline summarizes the most appropriate diagnostic tests for degenerative lumbar spondylolisthesis as well as the associated sequelae. Lateral x-ray is the most appropriate, noninvasive test for detecting the spondylolisthesis and should be obtained in an upright, weight-bearing position when possible.[71] Lateral lumbar flexion and extension radiographs may demonstrate instability of the lumbar spine associated with the spondylolisthesis.[72] Magnetic resonance imaging (MRI) is most appropriate for imaging spinal stenosis or facet joint effusion associated with spondylolisthesis. [71] "MRI provides a detailed view of the lumbar spine and conus medullaris. It is optimal for visualizing the soft tissue structures."[72] Plain myelography or computed tomography (CT) myelography is useful in assessing spinal stenosis or nerve root impingement associated with spondylolisthesis. [71] CT myelography is particularly useful when MRI is contraindicated or inconclusive. [71] "Myelography provides a comprehensive picture of the entire lumbar spine and has the advantage of being done in the standing position, which accentuates spinal stenosis."[72] When MRI and CT myelography are contraindicated or inconclusive, CT is useful in assessing spinal stenosis or nerve root impingement and provides a detailed view of the facet joint orientation. [71,72]

Chiropractic BioPhysics® and Lumbar Spondylolisthesis

Structural spinal rehabilitation has the unique ability to conservatively correct abnormal spinal alignment and posture. Spinal alignment and postural distortions result in adverse mechanical tension and distortion of tissue.[73] This adverse mechanical tension leads to degeneration of vertebral discs and facet joints.[73] Abnormal biomechanics leading to increased loading of the spine deleteriously affects processes such as tissue growth and repair.[74] Long term postural distortions place undue strain on the neural tissues surrounding these distortions.

Increasing tension in the spinal cord stresses the central nervous system by increasing intramedullary and cerebrospinal fluid pressure, coupled with a decrease in afferent and efferent nerve conduction.[74] In this case study, the patient's posture and spinal alignment were corrected and as a result, the lumbar lordosis and sagittal alignment were improved. By reducing the adverse gravitational loading from the patient's spondylolisthesis, aberrant stresses and strains on the neuromuscular tissues were minimized and so too were their associated symptoms.[23]

This case report suggests that structural spinal rehabilitation may be an effective conservative, non-surgical treatment for neuromusculoskeletal conditions such as spondylolisthesis, and associated symptoms including LBP and radiculopathy. Once more, structural spinal rehabilitation may serve as a preventative measure to degenerative spinal diseases and the consequences that arise from such pathologies. By using structural spinal rehabilitation, specifically Chiropractic BioPhysics®, to improve spinal alignment and postural distortions, the need for medical or invasive surgical procedures may be negated. More quality research is needed such as clinical trials involving structural spinal rehabilitation, surgical, and control groups with long-term follow-ups to see the results of discontinued care after improvement to determine any necessity for future treatments.

TEACHING POINT

Spondylolisthesis up to grade 2 may be reduced or corrected when using structural spinal rehabilitation. By using structural spinal rehabilitation to improve spinal alignment and postural abnormalities, the need for medical or invasive surgical procedures may be negated for patients with symptomatic spondylolisthesis up to grade 2.

REFERENCES

1. Haas JW, Harrison DD, Harrison DE, Oakley PA. Evidence-based protocol for structural rehabilitation of the spine and posture: review of clinical biomechanics of posture (CBP) publications. J Can Chiropr Assoc. 2005;49(4):270-96. PMID: 17549209.

2. Jackson BL, Harrison DD, Robertson GA, Barker WF. Chiropractic Biophysics Lateral Cervical Film Analysis. J Manipulative Physiol Ther. 1993;16(6):384-91. PMID: 8409786.

3. Troyanovich SJ, Robertson GA, Harrison DD, Holland B. Intra- and Interexaminer Reliability of the Chiropractic Biophysics Lateral Lumbar Radiographic Mensuration Procedure. J Manipulative Physiol Ther. 1995;18(8):519-24. PMID: 8583174.

4. Troyanovich SJ, Harrison DE, Harrison DD, Holland B, Janik TJ. Further Analysis of the Reliability of the Posterior Tangent Lateral Lumbar Radiographic Mensuration Procedure: Concurrent Validity of Computer Aided X-ray Digitization. J Manipulative Physiol Ther. 1998;21(7):460-7. PMID: 9777546.

5. Troyanovich SJ, Harrison SO, Harrison DD, Harrison DE, Payne M, Janik TJ, Holland B. Chiropractic Biophysics Digitized Radiographic Mensuration Analysis of the Anteroposterior Lumbar View: A Reliability Study. J Manipulative Physiol Ther. 1999; 22(5):309-15. PMID: 10395433.

6. Troyanovich SJ, Harrison DE, Harrison DD, Harrison SO, Janik TJ, Holland B. Chiropractic Biophysics Digitized Radiographic Mensuration Analysis of the Anteroposterior Cervicothoracic View: A Reliability Study. J Manipulative Physiol Ther. 2000;23(7):476-82. PMID: 11004652.

7. Harrison DE, Harrison DD, Cailliet R, Troyanovich SJ, Janik TJ, Holland B. Cobb Method or Harrison Posterior Tangent Method: Which is Better for Lateral Cervical Analysis? Spine. 2000;25(16):2072-8.

8. Harrison DE, Cailliet R, Harrison DD, Janik TJ, Holland B. Reliability of Centroid, Cobb or Harrison Posterior Tangent Methods: Which to Choose for Analysis of Thoracic Kyphosis? Spine. 2001;26(11):E227-34. PMID: 11389406.

9. Harrison DE, Cailliet R, Harrison DD, Janik TJ, Holland B. Radiographic Analysis of Lumbar Lordosis: Cobb Method, Centroidal Method, TRALL or Harrison Posterior Tangents? Spine. 2001;26(11):E235-42. PMID: 11389407.

10. Janik TJ, Harrison DE, Harrison, DD, Payne MR, Coleman RR, Holland B. Reliability of lateral bending and axial rotation with validity of a New Method to determine Axial Rotations on AP Radiographs. J Manipulative Physiol Ther. 2001;24(7):445-8. PMID: 11562652.

11. Harrison DE, Holland B, Harrison DD, Janik TJ. Further Reliability Analysis of the Harrison Radiographic Line Drawing Methods: Crossed ICCs for Lateral Posterior Tangents and AP Modified Risser-Ferguson. J Manipulative Physiol Ther. 2002;25:93-8. PMID: 11896376.

12. Harrison DE, Harrison DD, Colloca CJ, Betz JW, Janik TJ, Holland B. Repeatability Over Time of Posture, X-ray Positioning, and X-ray Line Drawing: An Analysis of Six Control Groups. J Manipulative Physiol Ther. 2003;26(2):87-98. PMID: 12584507.

13. Harrison DD, Janik TJ, Troyanovich SJ, Holland B. Comparisons of Lordotic Cervical Spine Curvatures to a Theoretical Ideal Model of the Static Sagittal Cervical Spine. Spine. 1996;21(6):667-75. PMID 8882687.

14. Harrison DD, Janik TJ, Troyanovich SJ, Harrison DE, Colloca CJ. Evaluations of the Assumptions Used to Derive an Ideal Normal Cervical Spine Model. J Manipulative Physiol Ther. 1997;20(4):246-56. PMID: 9168409.

15. Troyanovich SJ, Cailliet R, Janik TJ, Harrison DD, Harrison DE. Radiographic Mensuration Characteristics of the Sagittal Lumbar Spine From A Normal Population with a Method to Synthesize Prior Studies of Lordosis. J Spinal Disord. 1997;10(5):380-6. PMID: 9355053.

16. Harrison DD, Cailliet R, Janik TJ, Troyanovich SJ, Harrison DE, Holland B. Elliptical Modeling of the Sagittal Lumbar Lordosis and Segmental Rotation Angles as a Method to Discriminate Between Normal and Low Back Pain Subjects. J Spinal Disord. 1998; 11(5):430-9. PMID: 9811104.

17. Janik TJ, Harrison DD, Cailliet R, Troyanovich SJ, Harrison DE. Can the Sagittal Lumbar Curvature be Closely Approximated by an Ellipse? J Orthop Res. 1998;16(6): 766-70. PMID: 9877403.

18. Harrison DE, Janik TJ, Harrison DD, Cailliet R, Harmon S. Can the Thoracic Kyphosis be Modeled with a Simple Geometric Shape? The Results of Circular and Elliptical Modeling in 80 Asymptomatic Subjects. J Spinal Disord. 2002;15(3):213-20. PMID: 12131422.

19. Harrison DD, Harrison DE, Janik TJ, Cailliet R, Haas JW, Ferrantelli J, Holland B. Modeling of the Sagittal Cervical Spine as a Method to Discriminate Hypo-Lordosis: Results of Elliptical and Circular Modeling in 72 Asymptomatic Subjects, 52 Acute Neck Pain Subjects, and 70 Chronic Neck Pain Subjects. Spine. 2004;29:2485-92. PMID: 15543059.

20. McAviney J, Schulz D, Richard Bock R, Harrison DE, Holland B. Determining the relationship between cervical lordosis and neck complaints. J Manipulative Physiol Ther. 2005;28:187-93. PMID: 15855907.

21. Fedorchuk C, Opitz K. Improvement in quality of life and improved cervical curve in an 11-year-old child with asthma following chiropractic intervention: a case study. J Pediatr Matern & Fam Health - Chiropr. 2014;2014:37-46. PMID: None.

22. Bastecki A, Harrison DE, Haas J. Cervical kyphosis is a possible link to attention-deficit/hyperactivity disorder. J Manipulative Physiol Ther. 2004;27(8):e14. PMID: 15510091.

23. Troyanovich SJ, Harrison DD, Chiropractic biophysics (CBP) technique. Chiropr Tech. 1996;8(1):30-5. PMID: None.

24. Newman PH, Stone KH. The Etiology of Spondylolisthesis. Bone Joint J. 1963;45(1):39-59. PMID: None.

25. Kent C. Models of Vertebral Subluxation: A Review. J Vert Sublux Res. 1996;1(1):1-7. PMID: None.

26. Jacobsen S, Sonne-Holm S, Rovsing H, Monrad H, Gebuhr P. Degenerative lumbar spondylolisthesis: An epidemiological perspective. Spine. 2007;32(1):120-5. PMID: 17202902.

27. Kalichman L, Kim DH, Li L, Guermazi A, Berkin V, Hunter DJ. Spondylolysis and spondylolisthesis: prevalence and association with low back pain in the adult community-based population. Spine. 2009;34(2):199-205. PMID: 19139672.

28. He LC, Wang YX, Gong JS, Griffith JF, Zeng XJ, Kwok AW, Leung JC, Kwok T, Ahuja AT, Leung PC. Prevalence and risk factors of lumbar spondylolisthesis in elderly Chinese men and women. Eur Radiol. 2014;24(2):441-8. PMID: 24126641

29. Love TW, Fagan AB, Fraser RD. Degenerative spondylolisthesis. Developmental or acquired? J Bone Joint Surg Br. 1999;81(4):670-4. PMID: 10463743.

30. Devine JG, Schenk-Kisser JM, Skelly AC. Risk factors for degenerative spondylolisthesis: a systematic review. Evid Based Spine Care J. 2012;3(2):25-34. PMID: 23230415.

31. Korovessis P, Dimas A, Iliopoulos P, Lambiris E. Correlative Analysis of Lateral Vertebral Radiographic Variables and Medical Outcomes Study Short-Form Health Survey: A comparative study in asymptomatic volunteers versus patients with low back pain. Journal of Spinal Disorders & Techniques. 2002;15(5):384-90. PMID:12394662.

32. Kobayashi T, Takeda N, Atsuta Y, Matsuno T. Flattening of sagittal spinal curvature as a predictor of vertebral fracture. Osteoporos Int. 2008;19(1):65-9. PMID: 17874033.

33. Kado D, Huang M, Barret-Connor E, Greendale G. Hyperkyphotic posture and poor physical functional ability in older community-dwelling men and women: The Rancho Bernardo Study. J Gerontol A Biol Sci Med Sci 2005 May;60(5):633-7. PMID: 15972617.

34. Kado D, Huang M, Nguyen C, Barret-Connor E, Greendale G. Hyperkyphotic posture and risk of injurious falls in older persons: The Rancho Bernardo Study. J Gerontol A Biol Sci Med Sci 2007 Jun;62(6):652-7. PMID: 17595423.

35. Haldeman S. The evolution and importance of spinal and chiropractic research. J Manipulative Physiol Ther. 2015;15(1):31-5. PMID: 1740651.

36. Umehara S, Zindrick M, Patwardhan A, Havey R, Vrbos L, Knight G et al. The Biomechanical Effect of Postoperative Hypolordosis in Instrumented Lumbar Fusion on Instrumented and Adjacent Spinal Segments. Spine. 2000;25(13):1617-24. PMID: 10870136.

37. Adams M, McMillan D, Green T, Dolan P. Sustained Loading Generates Stress Concentrations in Lumbar Intervertebral Discs. Spine. 1996;21(4):434-8. PMID: 8658246.

38. Booth K, Bridwell K, Lenke L, Baldus C, Blanke K. Complications and Predictive Factors for the Successful Treatment of Flatback Deformity (Fixed Sagittal Imbalance). Spine. 1999;24(16):1712-20. PMID: 10472106.

39. Zencica P, Chaloupka R, Hladíková J, Krbec M. [Adjacent segment degeneration after lumbosacral fusion in spondylolisthesis: a retrospective radiological and clinical

analysis]. Acta Chir Orthop Traumatol Cech. 2010;77(2):124-30. PMID: 20447355.

40. Barrey C, Jund J, Noseda O, Roussouly P. Sagittal balance of the pelvis-spine complex and lumbar degenerative diseases. A comparative study about 85 cases. Eur Spine J. 2007;16(9):1459-67. PMID: 17211522.

41. Lü GH, Wang ZG, Wang B, Yin BL, Ma ZM, Liu WD, Li L, Kuang L, Yang F. [Relationship between variations of severe isthmic spondylolisthesis spino-pelvic parameters and clinical symptoms]. Zhonghua Yi Xue Za Zhi. 2013;93(15):1133-7. PMID: 23902880.

42. Wang Z, Wang B, Yin B, Liu W, Yang F, Lv G. The relationship between spinopelvic parameters and clinical symptoms of severe isthmic spondylolisthesis: a prospective study of 64 patients. Eur Spine J. 2014;23(3):560-8. PMID: 24142043.

43. Lim JK, Kim SM. Difference of Sagittal Spinopelvic Alignments between Degenerative Spondylolisthesis and Isthmic Spondylolisthesis. J Korean Neurosurg Soc. 2013;53(2):96-101. PMID: 23560173.

44. Labelle H, Roussouly P, Berthonnaud E, Dimnet J, O'Brien M. The importance of spino-pelvic balance in L5-s1 developmental spondylolisthesis: a review of pertinent radiologic measurements. Spine. 2005;30(6 Suppl):S27-34. PMID: 15767882.

45. Labelle H, Roussouly P, Berthonnaud E, Transfeldt E, O'Brien M, Chopin D, Hresko T, Dimnet J. Spondylolisthesis, pelvic incidence, and spinopelvic balance: a correlation study. Spine. 2004;29(18):2049-54. PMID: 15371707.

46. Loder RT. Profiles of the cervical, thoracic, and lumbosacral spine in children and adolescents with lumbosacral spondylolisthesis. J Spinal Disord. 2001 Dec;14(6):465-71. PMID: 11723394.

47. Funao H, Tsuji T, Hosogane N, Watanabe K, Ishii K, Nakamura M, Chiba K, Toyama Y, Matsumoto M. Comparative study of spinopelvic sagittal alignment between patients with and without degenerative spondylolisthesis. Eur Spine J. 2012;21(11):2181-7. PMID: 22639298.

48. Barrey C, Jund J, Perrin G, Roussouly P. Spinopelvic alignment of patients with degenerative spondylolisthesis. Neurosurgery. 2007;61(5):981-6. PMID: 18091275.

49. Ferrero E, Ould-Slimane M, Gille O, Guigui P; French Spine Society (SFCR). Sagittal spinopelvic alignment in 654 degenerative spondylolisthesis. Eur Spine J. 2015;24(6):1219-27. PMID: 25652553.

50. Rajnics P, Templier A, Skalli W, Lavaste F, Illés T. The association of sagittal spinal and pelvic parameters in asymptomatic persons and patients with isthmic spondylolisthesis. J Spinal Disord Tech. 2002;15(1):24-30. PMID: 11891447.

51. Liu H, Li S, Zheng Z, Wang J, Wang H, Li X. Pelvic retroversion is the key protective mechanism of L4-5 degenerative spondylolisthesis. Eur Spine J. 2015;24(6):1204-11. PMID: 24898313.

52. Barrey C, Jund J, Noseda O, Roussouly P. Sagittal balance of the pelvis-spine complex and lumbar degenerative diseases. A comparative study about 85 cases. Eur Spine J. 2007;16(9):1459-67. PMID: 17211522.

53. Lim JK, Kim SM. Comparison of Sagittal Spinopelvic Alignment between Lumbar Degenerative Spondylolisthesis and Degenerative Spinal Stenosis. J Korean Neurosurg Soc. 2014;55(6):331-6. PMID: 25237428.

54. Romano M, Negrini S. Manual therapy as a conservative treatment for adolescent idiopathic scoliosis: a systematic review. Scoliosis. 2008;3:2. PMID: 18211702.

55. Ferrantelli J, Harrison D, Harrison D, Stewart D. Conservative Treatment of a Patient With Previously Unresponsive Whiplash-Associated Disorders Using Clinical Biomechanics of Posture Rehabilitation Methods. J Manipulative Physiol Ther. 2005;28(3):e1-8. PMID: 15855899.

56. Harrison D, Harrison D, Betz J, Janik T, Holland B, Colloca C, et al. Increasing the cervical lordosis with chiropractic biophysics seated combined extension-compression and transverse load cervical traction with cervical manipulation: nonrandomized clinical control trial. J Manipulative Physiol Ther. 2003;26(3):139-51. PMID: 12704306.

57. Moustafa IM, Diab AA. Rehabilitation for Pain and Lumbar Segmental Motion in Chronic Mechanical Low Back Pain: A Randomized Trial. J Manipulative Physiol Ther. 2012;35(4):246-53. PMID: 22632584.

58. Moustafa IM, Diab AA. Extension traction treatment for patients with discogenic lumbosacral radiculopathy: a randomized controlled trial. Clin Rehabil. 2013;27(1):51-62. PMID: 22684211.

59. Diab AA, Moustafa IM. The efficacy of lumbar extension traction for sagittal alignment in mechanical low back pain. a randomized trial. J Back Musculoskelet Rehabil. 2013;26(2):213-22. PMID: 23640324.

60. Harrison DE, Harrison DD, Cailliet R, Janik TJ, Holland B. Changes in Sagittal Lumbar Configuration with a New Method of Extension Traction: Non-randomized Clinical Control Trial. Arch Phys Med Rehab 2002;83(11):1585-91. PMID: 12422330.

61. Harrison DE, Cailliet R, Betz JW, Harrison DD, Haas JW, Janik TJ, Holland B. Harrison Mirror Image Methods for Correcting Trunk List: A Non-randomized Clinical Control Trial. Eur Spine J 2004; Euro Spine J. 2005;14(2):155-62. PMID: 15517424.

62. Denard PJ, Holton KF, Miller J, Fink HA, Kado DM et al. Lumbar spondylolisthesis among elderly men: prevalence, correlates and progression. Spine. 2010;35(10):1072-8. PMID: 20393398.

63. Tosteson AA, Tosteson TD, Lurie JD, Abdu W, Herkowitz H et al. Comparative effectiveness evidence from the spine patient outcomes research trial: Surgical versus non-operative care for spinal stenosis, degenerative spondylolisthesis and intervertebral disc herniation. Spine. 2011;36(24):2061-8. PMID: 22048651.

64. Ong KL, Auerbach JD, Lau E, Schmier J, Ochoa JA. Perioperative outcomes, complications, and costs associated with lumbar spinal fusion in older patients with spinal stenosis and spondylolisthesis. Neurosurg Focus. 2014;36(6):E5. PMID: 24881637.

65. Weinstein JN, Lurie JD, Tosteson TD, Hanscom B, Tosteson AN et al. Surgical versus nonsurgical treatment for lumbar degenerative spondylolisthesis. New Engl J Med. 2007;356(22):2257-70. PMID: 17538085.

66. Vibert BT, Sliva CD, Herkowitz HN. Treatment of instability and spondylolisthesis: surgical versus nonsurgical treatment. Clin Orthop Relat Res. 2006;443:222-7. PMID: 16462445.

67. Excoffon SG, Wallace H. Chiropractic and rehabilitative management of a patient with progressive lumbar disk injury, spondylolisthesis, and spondyloptosis. J Manipulative Physiol Ther. 2006 Jan;29(1):66-71. PMID: 16396733.

68. Dunn AS, Baylis S, Ryan D. Chiropractic management of mechanical low back pain secondary to multiple-level lumbar spondylolysis with spondylolisthesis in a United States Marine Corps veteran: a case report. J Chiropr Med. 2009;8(3):125-30. PMID: 19703668.

69. Wong LC. Rehabilitation of a patient with a rare multi-level isthmic spondylolisthesis: a case report. J Can Chiropr Assoc. 2004;48(2):142-51. PMID: 17549226

70. Souza, T.A. Differential diagnosis and management for the chiropractor. Sudbury, MA: Jones and Bartlett Publishers; 2009.182-6. ISBN: 0763752827.

71. Matz PG, Meagher RJ, Lamer T, Tontz WL Jr, Annaswamy TM, Cassidy RC, Cho CH, Dougherty P, Easa JE, Enix DE, Gunnoe BA, Jallo J, Julien TD, Maserati MB, Nucci RC, O'Toole JE, Rosolowski K, Sembrano JN, Villavicencio AT, Witt JP. Guideline summary review: An evidence-based clinical guideline for the diagnosis and treatment of degenerative lumbar spondylolisthesis. Spine J. 2016;16(3):439-48. PMID: 26681351.

72. Herkowitz HN. Spine update. Degenerative lumbar spondylolisthesis. Spine. 1995;20(9):1084-90. PMID: 7631240.

73. Cooperstein R. Chiropractic biophysics (CBP). Chiropr Tech. 1995;7(4):141-6.

74. Troyanovich SJ, Harrison DE, Harrison DD. Structural rehabilitation of the spine and posture: rationale for treatment beyond the resolution of symptoms. J Manipulative Physiol Ther. 1998;21(1):37-50. PMID: 9467100.

FIGURES

Figure 1: 69-year-old female with low back pain (LBP) and a grade 2 spondylolisthesis.

Findings: Pre-treatment LL x-ray. LL projection demonstrates a grade 2 L4-L5 spondylolisthesis measuring 13.3 mm of anterior translation of L4 on L5 perpendicular from the posterior tangent of the L5 vertebral body to the posterior tangent of the L4 vertebral body.

Technique: 200mAs, 200mA, 86kVp, 40" FFD, Central Ray (CR) at L4.

Figure 2: 69-year-old female with low back pain (LBP) and a grade 2 spondylolisthesis.

Findings: Re-exam 1 LL x-ray after 11 weeks. LL projection demonstrates a grade 2 L4-L5 spondylolisthesis measuring 7.1 mm of anterior translation of L4 on L5 perpendicular from the posterior tangent of the L5 vertebral body to the posterior tangent of the L4 vertebral body.

Technique: 200mAs, 200mA, 86kVp, 40" FFD, CR at L4.

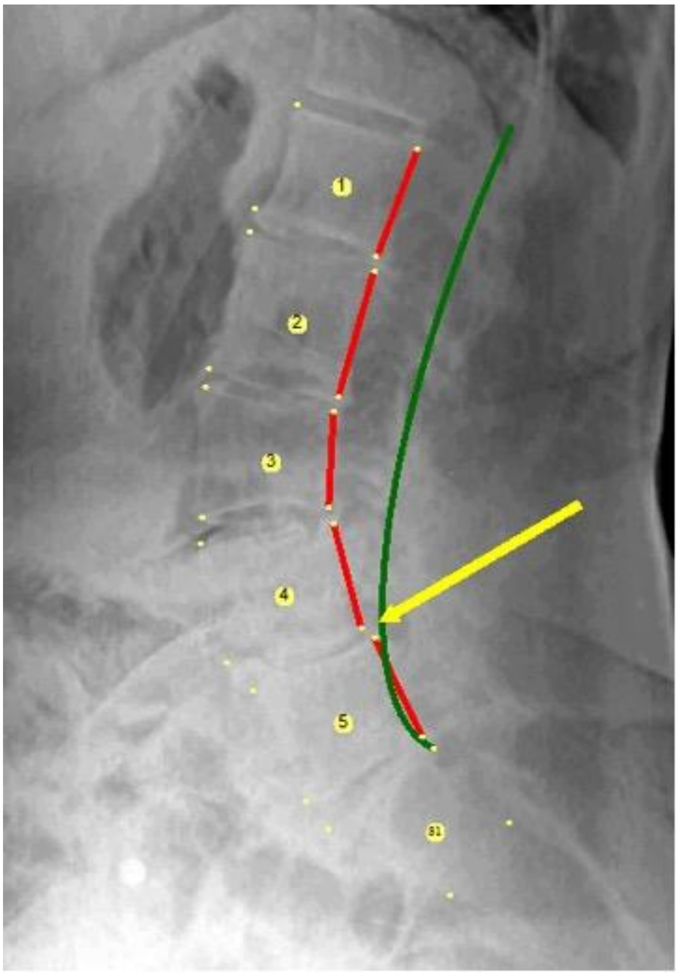

Figure 3: 69-year-old female with low back pain (LBP) and a grade 2 spondylolisthesis.

Findings: Re-exam 2 x-ray after 45 weeks. LL projection demonstrates 2.4 mm anterior translation of L4 on L5 perpendicular from the posterior tangent of the L5 vertebral body to the posterior tangent of the L4 vertebral body. This measurement is WNL.

Technique: 200mAs, 200mA, 86kVp, 40" FFD, CR at L4.

Measurement	Normal Values	Xray 1 Values	Xray 2 Values
RRA L1-L2	-5°	-7.5°	-5.4°
RRA L2-L3	-6°	-12.1°	-13.7°
RRA L3-L4	-9°	-16.0°	-18.5°
RRA L4-L5	-19°	-11.8°	-11.6°
RRA L5-S1	-33°	-14.8°	-15.6°
ARA L1-L5	-40°	-47.3°	-49.1°
SBA	40°	29.4°	33.5°
Tz L1-L2	0 mm	-1.1 mm	-0.5 mm
Tz L2-L3	0 mm	-1.0 mm	-0.8 mm
Tz L3-L4	0 mm	-0.5 mm	-0.8 mm
Tz L4-L5	0 mm	13.3 mm	7.1 mm
Tz L5-S1	0 mm	0.1 mm	0.5 mm
Tz L1-S1	0 mm	29.3 mm	25.1 mm

Table 1: PostureRay® Comparison Evaluation of Pre-Treatment and Re-Exam 1 LL X-rays.
Table 1 shows relative rotational angles (RRA) of measurement from L1 to S1, the sacral base angles (SBA), the translations in the z-axis (Tz) per segment from L1 to S1, and the Tz of L1 to S1 comparisons of pre-treatment and re-exam 1 lateral lumbar (LL) x-rays. SBA improved from 29.4° to 33.5° (normal is 40.0°), Tz L4-L5 improved from 13.3 mm to 7.1 mm (normal is 0.0 mm), and Tz L1-S1 improved from 29.3 to 25.1 (normal is 0.0 mm).RRA = Relative Rotational Angle of Measurement.
ARA = Absolute Rotational Angle of Measurement
SBA = Sacral Base Angle
Tz = Translation in the z-axis
* Tz in Red Exceed Established Normal
Xray 1 Values = Pre-treatment views
Xray 2 Values = Re-Exam 1 following 30 sessions over 11 weeks

Measurement	Normal Values	Xray 2 Values	Xray 3 Values
RRA L1-L2	-5°	-5.4°	-4.8°
RRA L2-L3	-6°	-13.7°	-13.6°
RRA L3-L4	-9°	-18.5°	-17.7°
RRA L4-L5	-19°	-11.6°	-11.3°
RRA L5-S1	-33°	-15.6°	-18.8°
ARA L1-L5	-40°	-49.1°	-47.4°
Sacral Base Angle	40°	33.5°	37.0°
Tz L1-L2	0 mm	-0.5 mm	0.0 mm
Tz L2-L3	0 mm	-0.8 mm	-0.3 mm
Tz L3-L4	0 mm	-0.8 mm	0.3 mm
Tz L4-L5	0 mm	7.1 mm	2.4 mm
Tz L5-S1	0 mm	0.5 mm	0.7 mm
Tz L1-S1	0 mm	25.1 mm	23.3 mm

Table 2: PostureRay® Comparison Evaluation of Re-Exam 1 and Re-Exam 2 LL X-rays
Table 2 shows RRAs from L1 to S1, SBAs, Tz per segment from L1 to S1, and Tz of L1 to S1 comparisons of re-exam 1 and re-exam 2 LL x-rays. SBA improved from 33.5° to 37.0° (normal is 40.0°) and Tz L4-L5 improved from 7.1 mm to 2.4 mm, within normal limits (WNL) (normal is 0.0 mm).
RRA = Relative Rotational Angle of Measurement
ARA = Absolute Rotational Angle of Measurement
Tz = Translation in the z-axis
* Tz in Red Exceed Established Normal
Xray 2 Values = Re-Exam 1 following 30 sessions over 11 weeks
Xray 3 Values = Re-Exam 2 following 60 sessions over 45 weeks

Measurement	Normal Values	Xray 1 Values	Xray 3 Values
RRA L1-L2	-5°	-7.5°	-4.8°
RRA L2-L3	-6°	-12.1°	-13.6°
RRA L3-L4	-9°	-16.0°	-17.7°
RRA L4-L5	-19°	-11.8°	-11.3°
RRA L5-S1	-33°	-14.8°	-18.8°
ARA L1-L5	-40°	-47.3°	-47.4°
Sacral Base Angle	40°	29.4°	37.0°
Tz L1-L2	0 mm	-1.1 mm	0.0 mm
Tz L2-L3	0 mm	-1.0 mm	-0.3 mm
Tz L3-L4	0 mm	-0.5 mm	0.3 mm
Tz L4-L5	0 mm	13.3 mm	2.4 mm
Tz L5-S1	0 mm	0.1 mm	0.7 mm
Tz L1-S1	0 mm	29.3 mm	23.3 mm

Table 3: Summary of PostureRay® Comparison Evaluation of Pre-Treatment and Re-Exam 2 LL X-rays.
Table 3 shows RRAs from L1 to S1, SBAs, Tz per segment from L1 to S1, and Tz of L1 to S1 comparisons of pre-treatment and re-exam 2 LL x-rays. RRA L5-S1 improved from -14.8° to -18.8° (normal is -33°), SBA improved from 29.4° to 37.0° (normal is 40.0°), Tz L4-L5 improved from 13.3 mm to 2.4 mm, WNL (normal is 0.0 mm), and Tz L1-S1 improved from 29.3 to 23.3 (normal is 0.0 mm).
RRA = Relative Rotational Angle of Measurement
ARA = Absolute Rotational Angle of Measurement
Tz = Translation in the z-axis
* Tz in Red Exceed Established Normal
Xray 1 Values = Pre-treatment views
Xray 3 Values = Re-Exam 2 following 60 sessions over 45 weeks

Spondylolisthesis	Summary
Etiology	• Translation of vertebra with respect to vertebra below • No modification to the pars interarticularis • Abnormal weight distribution, soft tissue laxity, and instability • Excessive joint play and buckling of the IVD posterior annular fibers • Abnormal spinal alignment and positional loading of the lumbar spine • May present with low back pain, radiculopathy, or no symptoms
Incidence	• 6-31% of the United States population suffers from degenerative spondylolisthesis
Gender Ratio	• Females:Males is 5:1.
Age Predilection	• Increase in prevalence from 50 to 90 years • 0% of <40-years-olds; 2.1% of 40–49-years-olds, 10.8% of 50–59-years-olds, 41.7% of 60–69-years-olds, and 16.7% of ≥70-years-olds
Risk Factors	• Increased age, sex, increased facet sagittalization, lumbar hypolordosis, increased BMI in females, and past pregnancies • Abnormal spinal alignment • Correlation with spinopelvic sagittal alignment factors
Treatment	• Spinal fusion surgery to stabilize • Non-surgical methods include active physical therapy, education or counseling for exercising, nonsteroidal anti-inflammatory drugs, homeopathic remedies, soft tissue massage, trigger point therapy, spinal mobilization techniques to restricted areas, cryotherapy, and chiropractic
Prognosis	• Degenerative condition unless the spine is stabilized
Findings on Imaging	• Most common level is L4-L5 • X-ray imaging shows extent of segmental translation • MRI shows extent of soft tissue damage

Table 4: Summary of Lumbar Spondylolisthesis in the Sagittal Plane.

	Plain Radiography	Magnetic Resonance Imaging	Computed Tomography (CT)	CT Myelography
Lumbar Spondylolisthesis	• Upright, weight bearing lateral lumbar view is most appropriate for detecting spondylolisthesis.[71] • Lateral lumbar flexion and extension views may demonstrate lumbar instability.[72]	• Most appropriate for imaging spinal stenosis or facet joint effusion. [71] • Provides a detailed view of the lumbar spine, conus medullaris, and soft tissue structures.[72]	• Useful when MRI and CT myelography are contraindicated or inconclusive. • Useful in assessing spinal stenosis or nerve roots and provides a detailed view of the facet joints. [71,72]	• Useful in assessing spinal stenosis or nerve roots and when MRI is contraindicated or inconclusive. [71] • Provides a view of the entire lumbar spine and is done in the standing position (accentuates spinal stenosis).[72]
Lumbar Compression Fracture	• Upright, weight bearing lateral lumbar view is most appropriate for detecting spondylolisthesis.[71] • Lateral lumbar flexion and extension views may demonstrate lumbar instability.[72]			
Lumbar Canal Stenosis		• Most appropriate for imaging spinal stenosis or facet joint effusion. [71] • Provides a detailed view of the lumbar spine, conus medullaris, and soft tissue structures.[72]	• Useful when MRI and CT myelography are contraindicated or inconclusive. • Useful in assessing spinal stenosis or nerve roots and provides a detailed view of the facet joints. [71,72]	• Useful in assessing spinal stenosis or nerve roots and when MRI is contraindicated or inconclusive. [71] • Provides a view of the entire lumbar spine and is done in the standing position (accentuates spinal stenosis).[72]
Lumbar Disc Herniation		• Most appropriate for imaging spinal stenosis or facet joint effusion. [71] • Provides a detailed view of the lumbar spine, conus medullaris, and soft tissue structures.[72]		
Lumbar Facet Arthropathy		• Most appropriate for imaging spinal stenosis or facet joint effusion. [71] • Provides a detailed view of the lumbar spine, conus medullaris, and soft tissue structures.[72]	• Useful when MRI and CT myelography are contraindicated or inconclusive. • Useful in assessing spinal stenosis or nerve roots and provides a detailed view of the facet joints. [71,72]	
Lumbar Spondylolysis	• Upright, weight bearing lateral lumbar view is most appropriate for detecting spondylolisthesis.[71] • Lateral lumbar flexion and extension views may demonstrate lumbar instability.[72]			

Table 5: Differential Diagnoses of Lumbar Spondylolisthesis in the Sagittal Plane and Appropriate Imaging.

Differential Diagnoses	Plain Radiography	Magnetic Resonance Imaging (MRI)	Computed Tomography (CT)	CT Myelography
	• Upright, weight bearing lateral lumbar view is most appropriate for detecting spondylolisthesis.[71] • Lateral lumbar flexion and extension views may demonstrate lumbar instability.[72]	• Most appropriate for imaging spinal stenosis or facet joint effusion. [71] • Provides a detailed view of the lumbar spine, conus medullaris, and soft tissue structures.[72]	• Useful when MRI and CT myelography are contraindicated or inconclusive. • Useful in assessing spinal stenosis or nerve roots and provides a detailed view of the facet joints. [71,72]	• Useful in assessing spinal stenosis or nerve roots and when MRI is contraindicated or inconclusive. [71] • Provides a view of the entire lumbar spine and is done in the standing position (accentuates spinal stenosis).[72]
Lumbar Spondylolisthesis	**X**	**X**	**X**	**X**
Lumbar Compression Fracture	**X**			
Lumbar Canal Stenosis		**X**	**X**	**X**
Lumbar Disc Herniation		**X**		
Lumbar Facet Arthropathy		**X**	**X**	
Lumbar Spondylolysis	**X**			

Table 6: Differential Diagnoses of Lumbar Spondylolisthesis in the Sagittal Plane and Appropriate Imaging (shortened table). X = indicates that the imaging procedure in the corresponding column is appropriate for the differential diagnosis in the corresponding row.

ABBREVIATIONS

° – degree
ADL – Activities of Daily Living
AP – Anterior-Posterior
ARA – Absolute Rotational Angle
BMI – Body Mass Index
CNS – Central Nervous System
CR – Central Ray
CT – Computed Tomography
FFD – Focal-Film Distance
HRQOL – Health-related Quality of Life
IVD – Intervertebral disc
kVp – kilovoltage peak
LBP – Low Back Pain
LL – Lateral Lumbar
mA – milliampere
mAs – milliampere second
mm – millimeter
MRI – Magnetic Resonance Imaging
NSAID – Non-steroidal Anti-inflammatory Drug
PA – Posterior-Anterior
PSF – Posterior Spine Fusions
PT – Physical Therapist
QALY – Quality-Adjusted Life Years
RRA – Relative Rotational Angle
SBA – Sacral base angle
Tz – Translation in the z-axis
WNL – Within Normal Limits

Spine Segment Shorthand
C_ – Cervical Region (7 vertebrae)
T_ – Thoracic Region (12 vertebrae)
L_ – Lumbar Region (5 vertebrae)
S_ – Sacral Region (4 vertebrae)
_# – the number of the vertebra in the spinal region numbered from superior to inferior

Spinal Alignment Shorthand
+/- _ _ _ – direction of movement per the Cartesian coordinate system
T_ _ – Translation along an axis per the Cartesian coordinate system
R _ _ – Rotation around an axis per the Cartesian coordinate system
_x_ – x-axis (in the body’s frontal plane) per the Cartesian coordinate system
_y_ – y-axis (in the body’s sagittal plane) per the Cartesian coordinate system
_z_ – z-axis (in the body’s transverse plane) per the Cartesian coordinate system
_ _ P – Pelvis (in relation to the feet)
_ _ T – Thoracic cage (in relation to the pelvis)
_ _ H – Head (in relation to the thoracic cage)
+TzT – Anterior Translation of the Thorax relative to the Pelvis

KEYWORDS

Mirror Image®; Chiropractic BioPhysics®; adjustment; traction; spinal alignment; posture; lumbar spondylolisthesis; anterolisthesis; vertebral subluxation; sacral base angle; lateral lumbar radiograph; lumbar spine