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S P T S

Case Study

Non-operative correction of flat back syndrome using lumbar extension traction: a CBP® case series of two

Deed E. Harrison[1]), Paul A. Oakley[2)*]

[1)] CBP NonProfit, Inc., USA
[2)] Private Practice: 11A-1100 Gorham Street, Newmarket, Ontario, L3Y8Y8, Canada

Abstract. [Purpose] To document the non-operative rehabilitation of lumbar lordosis in two cases with chronic low back pain and flexible flat back syndrome. [Participants and Methods] Two young adult males reported suffering from chronic low back pain associated with anterior sagittal balance and severe loss of lumbar lordosis, aka 'flat back syndrome.' Lumbar extension traction was applied 3–5 times per week for 16.5–20 weeks. A torsion type lumbar spinal manipulative therapy was provided in the initial 3 weeks for short-term pain relief. [Results] Both patients had dramatic improvement in lumbar lordosis with simultaneous reduction in pain levels. One patient had a 50° lordosis improvement in 100 treatments over 20 weeks; the other had a 26° lordosis improvement in 70 treatments over 16.5 weeks. There were also improvements in sacral base angle, pelvic tilt and sagittal balance. One patient demonstrated stability of health status and further improvements in radiographic measures including lordosis angle nearly 10-months post-treatment. [Conclusion] This is the first successful non-operative correction of flat back syndrome. This approach seems highly effective, is a fraction of the cost of spinal surgery typically used to treat this condition, and offers no health risks including those assumed from radiography necessary for screening and follow-up.
Key words: Flat back syndrome, Lumbar lordosis, Lumbar extension traction

INTRODUCTION

Contemporary spine care necessitates attention to both sagittal balance as well as sagittal spine alignment, where gross deviation of spine and postural balance is termed adult spinal deformity (ASD). The anterior translation of the upper body and gross loss (or kyphosis) of the lumbar spine is termed 'flat back syndrome' (FBS)[1–10].

Originally, FBS was used to describe the iatrogenic loss of the lumbar lordosis due to distraction instrumentation[3]. The flat back posture generally consists of an anterior displaced thorax or forward sagittal balance with marked decrease or kyphosis of the sagittal lumbar spine. FBS can be subdivided into several different types (causes) including: 1) iatrogenic; 2) degenerative/postural; 3) hip flexion contractures; 4) fixed thoracic hyper-kyphosis and or thoraco-lumbar kyphosis; 5) hormonal changes; 6) traumatically induced fractures; 7) insidious onset[1–4].

Further, FBS can be categorized into two broad types, fixed and flexible. As a rule, the fixed category is treated operatively by various techniques. Concerning the non-operative management of the fixed flat back, La Grone[3] suggested that exercises, bracing, non-steroidal anti-inflammatory agents, etc. have all proven unsuccessful. In contrast, although generally treated with operative methods, the flexible flat back spine might be successfully treated or corrected with rehabilitative methods. However, to date we could not locate any reports describing the successful correction of the flexible flat back spine utilizing non-operative methods. Obviously, the non-operative correction of the kyphotic lumbar spine would be an important alterna-

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*Corresponding author. Paul A. Oakley (E-mail: docoakley.icc@gmail.com)

Table 1. Comparison of X-ray measurements

Variable	Normal values	Case 1				Total chng	Case 2			Total chng
		Initial	Post 1	Post 2	f/u		Initial	Post 1	Post 2	
NPRS	0	8	3	1	1	−7	8.5	3	1	−7.5
No. txts	n/a	0	50	50	0	100	0	35	35	70
Weeks	n/a	n/a	10	10	38.5	58.5	n/a	8.5	8	16.5
TzT (T12-S1)	0 mm	54 mm	45 mm	22 mm	22 m	32 mm	72 mm	54 mm	30 mm	42 mm
L1-5 ARA	−40.2°	+14°	−10°	−24°	−36°	−50°	−12°	−26.5°	−28°	−16°
RRA L1-2	−3.2°	+3°	−6°	−8.5°	−7.5°	−10.5°	−13.5°	−10°	−7°	+6.5°
RRA L2-3	−7.9°	+7.5°	−2°	−2°	−1.5°	−9°	−1.5°	−10.5°	−8.5°	−7°
RRA L3-4	−12.3°	+6°	0°	−1.5°	−6.5°	−12.5°	+3.5°	0°	+1.5°	−2°
RRA L4-5	−16.7°	0°	−6°	−10.5°	−19.5°	−19.5°	+5°	−6.5°	−12°	−17°
RRA L5-S1	−33.0°	−11°	−15°	−20.5°	−18°	−7°	−18°	−16°	−21°	−3°
Ferguson	+39.4°	+8°	+26°	+23.5°	+36.5°	+28.5°	+18°	+28°	+31.5°	+13.5°
Pelvic tilt	+48.9°	0°	+11°	+24°	+29°	+29°	+24°	+32°	+36°	+12°

Sagittal balance of T12 to S1 (Tz), segmental angles (RRAs), global angles (ARA), pelvic tilt, and sacral base angle to horizontal (Ferguson) at initial examination (initial), and follow-up assessments (post 1; post 2; f/u).

tive to a subset of patients with the FBS.

We report on the successful non-operative management of two cases suffering from low back pain (LBP) being diagnosed with the flexible-type flat back lumbar spine syndrome. One case was a degenerative type; the other was an insidious onset of flat back.

PARTICIPANTS AND METHODS

A retrospective review of two patients with complete loss or kyphotic alignment of the lumbar lordosis and anterior translation of the thorax relative to the pelvis are presented. Both were treated with short-term lumbar spine manipulation for pain-relief[7] and long-term treatment with lumbar extension traction based on the three-point bending principle[11]. Both patients were male, 27 and 31 years of age, 177 cm and 181 cm in height, and 79 kg and 89 kg in weight, respectively.

Both patients were evaluated with a history and physical exam. A numerical pain rating scale (NPRS: 0=no pain; 10=worst pain ever) was used to rate the intensity of perceived pain (Table 1). The history and physical exam were completed at the beginning and at all follow-up evaluations. Both participants were free from 1) prior lumbar spinal surgery; 2) any congenital anomaly causing fixed sagittal imbalance; 3) any type of lumbar spine fracture causing fixed sagittal imbalance.

All lumbar lordosis measurements used the Harrison posterior tangent method which has high reliability and small absolute differences of observers' measurements[12, 13]. This method uses lines drawn along the posterior vertebral body margins from L1–5 (global 'absolute rotation angle' ARA) and for each intersegmental angle ('relative rotation angle' RRA) from L1–2 to L5–S1 (a negative sign designates extension/lordosis, a positive sign flexion/kyphosis). Ferguson's sacral base angle (to horizontal) was measured as well as pelvic tilt angle (angle between horizontal and a line from posterior-inferior S1 to the superior margin of the acetabulum). Sagittal balance, or sagittal translation was measured by comparing the horizontal displacement from a line drawn connecting the posterior inferior body corner of T12 to the posterior inferior of S1 (anterior translation of T12 is assigned as positive, posterior translation is negative).

Case 1 was a 27 year old male complaining of chronic LBP. His symptoms were constant, moderate and disabling and he rated the pain as an 8/10 (ranging from 5–8/10) on the NPRS; there was radiation of pain into the posterior of both thighs ending at the knee. This patient had tried numerous other treatments including physical therapy and chiropractic and had no success. The pain was so great that he noticed marked disability in his activities of daily living. Previously he had been recommended for surgery as he had thought he had exhausted all treatment options.

On physical exam the patient exhibited a marked anterior displaced thoracic posture. There were no signs of sensory or motor deficits. All thoracic and lumbar ranges of motion were normal except for a marked decrease in lumbar extension that produced pain. The straight leg raiser test produced moderate LBP with increased radiation of pain into both thighs.

A radiographic examination revealed an L1–L5 ARA of +14° (normal=−40°[14, 15]), a sacral base to horizontal (Ferguson angle) of −8° (normal=+39.4°[15]) and a sagittal translation distance of T_{12}–S_1 of +54 mm (normal=0 mm[10]) (Fig. 1). The relative rotation angles (RRAs) and pelvic tilt angle are reported in Table 1.

Case 2 was a 31 year old male with chronic LBP. He reported pain as sharp and severe, scored an 8.5/10 NPRS with radiation of pain into the right gluteal area increasing in frequency, duration and intensity over the past three years. Two months prior to treatment, the patient was placed on temporary work disability. The patient was on Valium, Norpramin and Diazepam for the treatment of his pains.
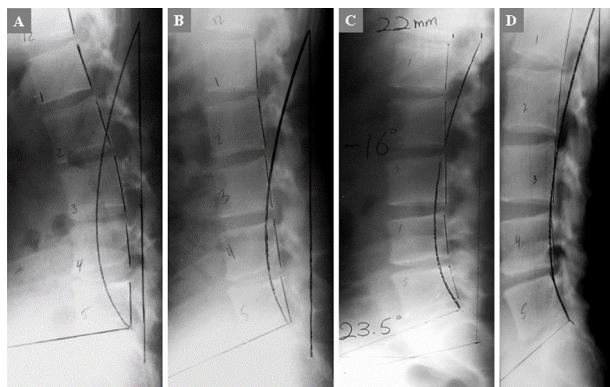
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Fig. 1. Patient 1. The vertical black line represents the ideal sagittal alignment of the posterior inferior body of T12 relative to the origin at the posterior inferior body of S1. The black ellipse represents the ideal curvature of the posterior vertebral body margins of L1–L5. The black line at the posterior body margins of L1–L5 represents the patient's lumbar curvature. A, Initial lumbar alignment. B, 10 week post treatment lumbar alignment after 50 treatments. C, 20 week post treatment lumbar alignment after 100 treatments. D, 38.5 week follow-up lumbar alignment.
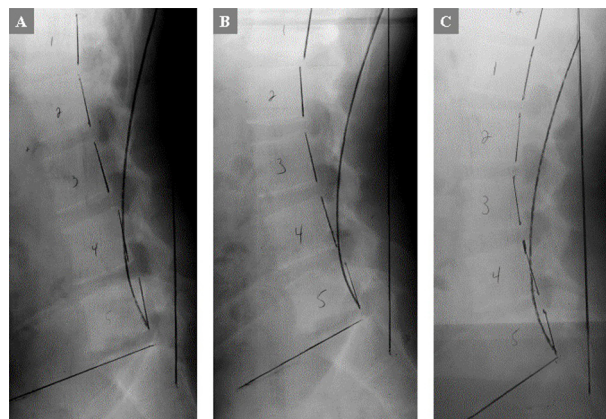

Fig. 2. Patient 2. The vertical black line represents the ideal sagittal alignment of the posterior inferior body of T12 relative to the origin at the posterior inferior body of S1. The black ellipse represents the ideal curvature of the posterior vertebral body margins of L1–L5. The black line at the posterior body margins of L1–L5 represents the patient's lumbar curvature. A, Initial lumbar alignment. B, 8.5 week post treatment lumbar alignment after 35 treatments. C, 16.5 week post-treatment lumbar alignment after a total of 70 treatments.

On physical examination the patient had decreases in all thoracic and lumbar ranges of motion. Motor evaluation of the lower extremity revealed decreased strength for the L1–L4 myotomes (+4). Deep tendon reflexes were normal. A positive minors sign was noted. Lateral lumbar x-ray revealed an L1–L5 ARA of −12° with a mid lumbar kyphosis (Fig. 2). The sacral base angle was −18° and the sagittal translation distance of T_{12}–S_1 was +72 mm. RRA's and angle of pelvic tilt were also measured (Table 1).

The treatment given for both cases was Chiropractic BioPhysics® (CBP®) posture and spine rehabilitation procedures[16–18]. CBP is a full-spine corrective approach to re-align the posture and spine towards a more normal/ideal configuration[10, 14, 15, 19–23] (i.e. normal cervical and lumbar lordosis, thoracic kyphosis, no postural translations/rotations, and vertical anteroposterior/lateral spinal balance)[16–18, 24]. Typically, mirror image exercises, spinal manipulative therapy and traction methods are incorporated into the treatment protocol.

Regarding the lumbar lordosis, lumbar extension traction is used to restore lordosis to the elliptical normal L1–L5 ARA value of −40°. Lumbar extension 3-point bending traction was performed in the supine position. An anterior pull strap was applied between the upper torso and lower pelvis (Fig. 3). The legs were extended keeping the feet at the same level as the pelvis, this effectively creates increased strain on the hamstring muscles, which is related to changing the lumbar lordosis[8, 9]. The padded strap around the posterior aspect of the low back is attached to a spreader bar, cable, and pulley. Tension was applied according to patient tolerance. The angle of the posterior to anterior low back pull relative to vertical is varied depending upon the participants' apex of lumbar curve alignment; an upper to mid lumbar kyphosis has predominantly a vertical pull, while a lower lumbar kyphosis has an angle of pull about 15–20° caudally in order to create the elliptical lumbar configuration with increased distal lumbar curve as suggested by Janik et al[10]. A Velcro strap attached to the traction baseplate was secured around the participants' femurs to allow for increased forward rotation of the pelvis to occur when tension is applied to the lumbar pull.

Traction duration began at 3 minutes, increased one minute per session until 20 minutes was reached, at which time 20 minutes per session was applied. The magnitude of the traction force varied depending upon the tolerance of the particular patient. When familiar with the traction, each of the participants were encouraged to use the maximum tolerable force.

Standard lateral lumbar radiographs were obtained where the participants were asked to stand straight but relaxed and the arms were folded across the chest and all post-treatment lateral lumbar radiographs were taken a minimum of 24 hours after the last traction session.

Both patients were given lumbar spinal manipulative therapy for initial symptomatic relief during the first 2–3 weeks, and were treated 4–5 times per week. This study received IRB approved waiver of informed consent through IntegReview IRB (www.integreview.com) on March 22, 2018 (protocol No. CBP2018-001).

Fig. 3. Lumbar extension traction set-up. The patient is supine with the legs extended. The upper thighs are constrained down to the traction frame while the lumbar spine is pulled in a Posterior to Anterior direction. The location of the lumbar strap is placed at the apex of the lumbar kyphosis. The angle of pull is changed from vertical to slightly inferior towards the feet depending upon an upper, middle or lower lumbar kyphosis, respectively.

RESULTS

Case 1 was given 50 treatments over the first 10 weeks. At first post-treatment assessment the patient claimed to have an increase in the ability to take part in activities of daily living, reported a marked improvement in NPRS (3/10 vs. 8/10), had an increase in lumbar lordosis (−10° vs. +14°), increase in sacral base angle (26° vs. 8°), and reduced anterior sagittal balance (45 mm vs. 54 mm) (Fig. 1). The patient was treated another 50 times over a further 10 weeks showing continued reduction of pain (1/10 vs. 8/10), increase in lordosis (−24° vs. +14°), a preserved sacral base angle (23.5° vs. 8°), and further reduction of sagittal balance (22 mm vs. 54 mm). The patient returned for a follow-up evaluation 38.5 weeks following the termination of the initial 20-weeks worth of treatment, and demonstrated to be well scoring a 1/10 NPRS and had a further increase in lumbar lordosis of 12° (−36° vs. +14° initially) as well as a further increase in sacral base angle (36.5° vs. 29° initially) and a maintenance of sagittal balance (Fig. 1; Table 1). Interestingly, all radiographic parameters demonstrated stability or further improvement, without treatment at the follow-up (Table 1).

Case 2 was given 35 treatments over 8.5 weeks. The first post-treatment exam showed an increase in lumbar ROM and normalization of lower extremity strength, a reduced NPRS (3/10 vs. 8/10) and an increased lumbar lordosis (−26.5° vs. −12°). Improvements in sacral base angle (28° vs. 18°) and reduction of anterior sagittal balance (54 mm vs. 72 mm) were also noted (Fig. 2). The patient was placed on a second treatment program of 35 treatments over an additional 8 weeks which led to continued improvements in NPRS (1/10 vs. 8.5/10), increased lordosis (−28° vs. −12°), reduced sagittal balance (30 mm vs. 72 mm), and an increased sacral base (31.5° vs. 18°) (Fig. 2). All ROM and orthopedic tests became unremarkable.

DISCUSSION

Treatment with lumbar extension traction as a part of the CBP rehabilitation program resulted in large increases in sagittal lumbar lordosis, decreased anterior sagittal balance and a minimization of pain levels in two patients diagnosed with FBS suffering from chronic LBP.

According to Booth et al.[1], regarding the surgical correction of the flat back spine, increasing the lordosis, angle of pelvic tilt, and improving the sagittal balance to neutral or posterior alignment are important factors in preventing future disability and pain in patients with this syndrome. Surgical procedures for the iatrogenic flat back spine have demonstrated improvements of lumbar lordosis ranging from 20–29°, and changes in sagittal balance of 26–66 mm[1]. The improvements obtained in the two cases report here are close to this range, with case 1 having a total increase of 50° in lumbar lordosis and a 22 mm reduction in anterior sagittal balance, and case 2 having a 16° increase in lordosis and a 42 mm decrease in anterior sagittal balance (Table 1).

There have been three clinical trials reported on lumbar extension traction methods. In a prospective non-randomized clinical control trial, after an average of 36 treatments with extension traction, Harrison et al.[11] found an average increase of 11.3° (L1–5 ARA) in lumbar lordosis in 48 participants with chronic low back pain and reduced lumbar lordosis. Moustafa et al.[25], reported a mean increase of 8.7° (L1–L5 ARA) increase in lumbar lordosis in 30 treatments of lumbar extension traction as a part of a rehabilitation program over 10 weeks in 32 patients suffering from lumbosacral radiculopathy. Diab and Moustafa[26, 27] reported on the 3, and 6-months follow-up on 40 patients with chronic mechanical LBP treated with lumbar extension traction 30 times as part of a rehabilitation program and found a 7° (L1–S1 ARA) increase in lumbar lordosis.

The lordosis increases in the current two cases are much larger than those obtained in the previous reported clinical trials[11, 25–27] and is likely the result of two factors: 1) the larger sagittal plane deformity in our two participants with flat back syndrome; 2) the increased number of treatments to the patients in the current study. Concerning the first point, the

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mentioned trials treated patients with hypolordosis and not deformities as grossly deviated from ideal/normal as in the current two patients; thus, the larger the deformity, the greater the potential for correction. Regarding the second point, the mentioned trials treated patients for only 30–36 treatments, where our two cases received 70 and 100 treatments. As discussed by Oakley et al.[17], treatment using lumbar extension traction should be continued until the desired lumbar alignment (i.e. L1–L5 ARA=−40°[10, 14, 15]) is attained; and consistent with the first point, the larger the deformity, the more treatments necessary to restore normality to the sagittal lumbar alignment. This is an example of the application of evidence in practicing evidence-based medicine.

It should be noted that in the Harrison et al. trial[11] matched control group no changes in lordosis were noted on radiographs taken 8–9 months apart. Also in the Moustafa et al.[25] and Diab et al.[26, 27] trials, there were comparison groups who received 'conventional' rehabilitation but not lumbar extension traction methods, and these groups did not have a change in their lordosis measurements. The stability of the lumbar lordosis over time has been documented[28, 29] and this evidence points to a treatment effect of lumbar extension traction increasing lordosis and not merely errors in positioning during radiographic examination.

How does lumbar extension traction increase lordosis? We suggest that lumbar extension traction creates a deformation in the soft tissues (muscles, ligaments, and discs) of the lumbar spine. Tendons, ligaments, and discs, all display visco-elastic properties[30]. When the soft tissues of the spine are subjected to a sustained load for a given time, these tissues undergo two major processes, creep and stress relaxation. Creep is the amount of deformation occurring in the tissues and stress relaxation is a reduction in the amount of the internal stress found in the tissue over time[30–34].

In extension creep loading of cadaveric lumbar specimens, during the first 5 minutes much of the initial deformation is recoverable strain energy (elastic). Most of the non-recoverable strain (permanent deformation) energy takes place from 5 to 20 minutes; at 20 minutes a plateau effect takes place. It is the non-recoverable strain energy that results in the permanent deformation or resting length change of the spinal tissues[33, 34]. The two patients in this study performed extension traction for 20 minutes to take advantage of the visco-elastic deformation in the spinal tissues.

When attempting to critically analyze any new form of treatment, it is important to look at the cost of these procedures in relation to other procedures aimed at the same result. The average cost of a lumbar fusion has been estimated to be around $62,300[35, 36]. For the non-operative management of the flexible flat back syndrome as demonstrated in this paper, a range of costs have been calculated. The least number of treatments in this study was 70 visits, and the greatest, 100 visits. The average cost of a treatment in the office where these patients were treated ranged from $25 to $50 and the cost of the examinations were $45 (4 for case 1; 3 for case 2) plus lumbar spinal radiography $50 (4 for case 1; 3 for case 2). Using this data, a cost range of $725–$5,000 can be obtained. The cost of the non-operative treatment of the flat back spine in this report is approximately 1.1–8.0% of the costs of the surgical alternative. This cost is within the range of that report by Nelson et al.[36] for a rehabilitation program aimed at the prevention of spinal surgery in a subset of patients. Thus, at first 70 or 100 treatments may be criticized as 'over-treatment,' however, considering the overall cost-effectiveness and positive patient outcomes, it certainly is not; in fact, both patients should have received more treatment as both were short of achieving a final lumbar lordosis to the normal L1–L5 ARA of −40°.

It should be mentioned that this type of treatment (extension traction) necessitates radiographic imaging, much like surgical approaches to spinal deformity correction. Traditionally, radiation exposure including that from diagnostic x-rays have been viewed as dangerous based on risk assessment from the major organizations (i.e. NAS, ICRP, BEIR, etc.)[37]. However, all these associations have incorporated the linear no-threshold (LNT) model or hypothesis to extrapolate in a linear fashion high-dose atomic bomb data down to the zero-dose; thus in the absence of any data, x-rays are assumed harmful. The LNT model had been determined to be false[38–41], as its main supporting data has recently been shown to better fit a linear-quadratic relationship (not linear)[42] and therefore, the LNT no longer has evidence to support its use. The ALARA concept ('As Low As Reasonably Achievable') as used in medical radiation safety is also no longer valid[43–47]. Therefore, any x-ray use in the assessment and treatment of spinal deformity are in the very low-dose range of radiation exposures, and their use presents no harm to patients.

There are several limitations to this case series needing discussion. First, there were only two participants, therefore, future verification of these results are needed and recommended. Second, when comparing the costs of treating these two patients to surgery, it may be argued that these two cases are not typical surgical candidates, for example, the age (27; 31) of these participants is generally well below that of previous reports concerning iatrogenic and degenerative flat back participants[1–4]. Kyphotic deformities of the sagittal lumbar spine, however, are known to predispose those having them to long-term degenerative changes[5, 6], and therefore, it is more than likely these two patients would have progressed into operative candidates; in fact, one of the patients was offered surgery but refused.

Third, only one of the two cases was available for long-term follow-up. Although the results from the follow-up in case 1 was ideal, it is unknown what the prognosis may be a longer time into the future, and it is unknown what the stability was in case 2. Last, it is possible that the 2–3 week treatment with lumbar spine manipulative therapy might be responsible for some of the initial pain improvements and sagittal alignment changes, however, in general, there is no evidence that spinal manipulation is capable of improving the alignment of the sagittal lumbar spine[11]. Also, there is only limited evidence that spinal manipulation is of benefit to patients with chronic lower back pain[7]. The trials from Moustafa et al. and Diab et al.[25–27] have substantiated that lordosis improvements are solely the result of lumbar extension traction methods.

Conflict of interest

PAO is paid by CBP NonProfit for writing the manuscript; DEH teaches rehabilitation methods and sells products to physicians for patient care as used in this manuscript.

REFERENCES

1) Booth KC, Bridwell KH, Lenke LG, et al.: Complications and predictive factors for the successful treatment of flatback deformity (fixed sagittal imbalance). Spine, 1999, 24: 1712–1720. [Medline] [CrossRef]

2) Engsberg JR, Bridwell KH, Reitenbach AK, et al.: Preoperative gait comparisons between adults undergoing long spinal deformity fusion surgery (thoracic to L4, L5, or sacrum) and controls. Spine, 2001, 26: 2020–2028. [Medline] [CrossRef]

3) La Grone MO: Loss of lumbar lordosis. A complication of spinal fusion for scoliosis. Orthop Clin North Am, 1988, 19: 383–393. [Medline]

4) Lee CS, Lee CK, Kim YT, et al.: Dynamic sagittal imbalance of the spine in degenerative flat back: significance of pelvic tilt in surgical treatment. Spine, 2001, 26: 2029–2035. [Medline] [CrossRef]

5) Oda I, Cunningham BW, Buckley RA, et al.: Does spinal kyphotic deformity influence the biomechanical characteristics of the adjacent motion segments? An in vivo animal model. Spine, 1999, 24: 2139–2146. [Medline] [CrossRef]

6) Umehara S, Zindrick MR, Patwardhan AG, et al.: The biomechanical effect of postoperative hypolordosis in instrumented lumbar fusion on instrumented and adjacent spinal segments. Spine, 2000, 25: 1617–1624. [Medline] [CrossRef]

7) Koes BW, van Tulder MW, Ostelo R, et al.: Clinical guidelines for the management of low back pain in primary care: an international comparison. Spine, 2001, 26: 2504–2513, discussion 2513–2514. [Medline] [CrossRef]

8) McCarthy JJ, Betz RR: The relationship between tight hamstrings and lumbar hypolordosis in children with cerebral palsy. Spine, 2000, 25: 211–213. [Medline] [CrossRef]

9) Stokes IA, Abery JM: Influence of the hamstring muscles on lumbar spine curvature in sitting. Spine, 1980, 5: 525–528. [Medline] [CrossRef]

10) Janik TJ, Harrison DD, Cailliet R, et al.: Can the sagittal lumbar curvature be closely approximated by an ellipse? J Orthop Res, 1998, 16: 766–770. [Medline] [CrossRef]

11) Harrison DE, Cailliet R, Harrison DD, et al.: Changes in sagittal lumbar configuration with a new method of extension traction: nonrandomized clinical controlled trial. Arch Phys Med Rehabil, 2002, 83: 1585–1591. [Medline] [CrossRef]

12) Harrison DE, Harrison DD, Cailliet R, et al.: Radiographic analysis of lumbar lordosis: centroid, Cobb, TRALL, and Harrison posterior tangent methods. Spine, 2001, 26: E235–E242. [Medline] [CrossRef]

13) Harrison DE, Holland B, Harrison DD, et al.: Further reliability analysis of the Harrison radiographic line-drawing methods: crossed ICCs for lateral posterior tangents and modified Risser-Ferguson method on AP views. J Manipulative Physiol Ther, 2002, 25: 93–98. [Medline] [CrossRef]

14) Troyanovich SJ, Cailliet R, Janik TJ, et al.: 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: 380–386. [Medline] [CrossRef]

15) Harrison DD, Cailliet R, Janik TJ, et al.: 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: 430–439. [Medline] [CrossRef]

16) Harrison DD, Janik TJ, Harrison GR, et al.: Chiropractic biophysics technique: a linear algebra approach to posture in chiropractic. J Manipulative Physiol Ther, 1996, 19: 525–535. [Medline]

17) Oakley PA, Harrison DD, Harrison DE, et al.: 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: 270–296. [Medline]

18) Harrison DE, Betz JW, Harrison DD, et al.: CBP structural rehabilitation of the lumbar spine: Harrison Chiropractic Biophysics Seminars, Inc. 2007.

19) Harrison DD, Janik TJ, Troyanovich SJ, et al.: Comparisons of lordotic cervical spine curvatures to a theoretical ideal model of the static sagittal cervical spine. Spine, 1996, 21: 667–675. [Medline] [CrossRef]

20) Harrison DD, Janik TJ, Troyanovich SJ, et al.: Evaluation of the assumptions used to derive an ideal normal cervical spine model. J Manipulative Physiol Ther, 1997, 20: 246–256. [Medline]

21) Harrison DE, Janik TJ, Harrison DD, et al.: Can the thoracic kyphosis be modeled with a simple geometric shape? The results of circular and elliptical modeling in 80 asymptomatic patients. J Spinal Disord Tech, 2002, 15: 213–220. [Medline] [CrossRef]

22) Harrison DD, Harrison DE, Janik TJ, et al.: Do alterations in vertebral and disc dimensions affect an elliptical model of thoracic kyphosis? Spine, 2003, 28: 463–469. [Medline] [CrossRef]

23) Harrison DD, Harrison DE, Janik TJ, et al.: Modeling of the sagittal cervical spine as a method to discriminate hypolordosis: results of elliptical and circular modeling in 72 asymptomatic subjects, 52 acute neck pain subjects, and 70 chronic neck pain subjects. Spine, 2004, 29: 2485–2492. [Medline] [CrossRef]

24) Harrison DE, Harrison DD, Troyanovich SJ: Three-dimensional spinal coupling mechanics: Part II. Implications for chiropractic theories and practice. J Manipulative Physiol Ther, 1998, 21: 177–186. [Medline]

25) Moustafa IM, Diab AA: Extension traction treatment for patients with discogenic lumbosacral radiculopathy: a randomized controlled trial. Clin Rehabil, 2013, 27: 51–62. [Medline] [CrossRef]

26) Diab AA, Moustafa IM: Lumbar lordosis rehabilitation for pain and lumbar segmental motion in chronic mechanical low back pain: a randomized trial. J Manipulative Physiol Ther, 2012, 35: 246–253. [Medline] [CrossRef]

27) Diab AA, Moustafa IM: The efficacy of lumbar extension traction for sagittal alignment in mechanical low back pain: a randomized trial. J Back Musculoskeletal Rehabil, 2013, 26: 213–220. [Medline] [CrossRef]

28) Harrison DE, Harrison DD, Colloca CJ, et al.: Repeatability over time of posture, radiograph positioning, and radiograph line drawing: an analysis of six control groups. J Manipulative Physiol Ther, 2003, 26: 87–98. [Medline] [CrossRef]

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29) Jackson RP, Kanemura T, Kawakami N, et al.: Lumbopelvic lordosis and pelvic balance on repeated standing lateral radiographs of adult volunteers and untreated patients with constant low back pain. Spine, 2000, 25: 575–586. [Medline] [CrossRef]

30) Panjabi MM, White AA: Biomechanics in the musculoskeletal system. Churchill Livingstone, 2001.

31) Adams MA, Dolan P: Time-dependent changes in the lumbar spine's resistance to bending. Clin Biomech (Bristol, Avon), 1996, 11: 194–200. [Medline] [CrossRef]

32) Hukins DW, Kirby MC, Sikoryn TA, et al.: Comparison of structure, mechanical properties, and functions of lumbar spinal ligaments. Spine, 1990, 15: 787–795. [Medline] [CrossRef]

33) Oliver MJ, Twomey LT: Extension creep in the lumbar spine. Clin Biomech (Bristol, Avon), 1995, 10: 363–368. [Medline] [CrossRef]

34) Woo S, Livesay GA, Runco TJ, et al.: Structure and function of tendons and ligaments. In: Mow VC, Hayes WC, Eds. Basics Orthopaedic Biomechanics, 2nd ed. Philadeophia: Lippincott-Raven, 1997: pp 209–252.

35) National Council on Compensation Insurance: Workers compensation back claim study. Baca Raton: NCCI, 1993.

36) Nelson BW, Carpenter DM, Dreisinger TE, et al.: Can spinal surgery be prevented by aggressive strengthening exercises? A prospective study of cervical and lumbar patients. Arch Phys Med Rehabil, 1999, 80: 20–25. [Medline] [CrossRef]

37) Committee to assess health risks from exposure to low levels of ionizing radiation: National Research Council. Health risks from exposure to low levels of ionizing radiation: BEIR VII, phase 2. Washington DC: National Academies Press, 2006.

38) Siegel JA, Pennington CW, Sacks B: Subjecting radiologic imaging to the linear no-threshold hypothesis: a non sequitur of non-trivial proportion. J Nucl Med, 2017, 58: 1–6. [Medline] [CrossRef]

39) Sacks B, Siegel JA: Preserving the anti-scientific linear no-threshold myth: authority, agnosticism, transparency, and the standard of care. Dose Response, 2017, 15: 1559325817717839. [Medline] [CrossRef]

40) Sacks B, Meyerson G, Siegel JA: Epidemiology without biology: false paradigms, unfounded assumptions, and specious statistics in radiation science (with commentaries by Inge Schmitz-Feuerhake and Christopher Busby and a reply by the authors). Biol Theory, 2016, 11: 69–101. [Medline] [CrossRef]

41) Siegel JA, Welsh JS: Does imaging technology cause cancer? Debunking the linear no-threshold model of radiation carcinogenesis. Technol Cancer Res Treat, 2016, 15: 249–256. [Medline] [CrossRef]

42) Ozasa K, Shimizu Y, Suyama A, et al.: Studies of the mortality of atomic bomb survivors, report 14, 1950-2003: an overview of cancer and noncancer diseases. Radiat Res, 2012, 177: 229–243. [Medline] [CrossRef]

43) Doss M: Disavowing the ALARA concept in pediatric imaging. Pediatr Radiol, 2017, 47: 118. [Medline] [CrossRef]

44) Cohen MD: Reply to Dr. Andronikou: disavowing the ALARA concept in pediatric imaging. Pediatr Radiol, 2017, 47: 116–117. [Medline] [CrossRef]

45) Siegel JA, McCollough CH, Orton CG: Advocating for use of the ALARA principle in the context of medical imaging fails to recognize that the risk is hypothetical and so serves to reinforce patients' fears of radiation. Med Phys, 2017, 44: 3–6. [Medline] [CrossRef]

46) Andronikou S: Letting go of what we believe about radiation and the risk of cancer in children. Pediatr Radiol, 2017, 47: 113–115. [Medline] [CrossRef]

47) Doss M: Should the ALARA concept and the Image Gently campaign be terminated? Paper presented at the International Pediatric Radiology 2016, Chicago, IL, May 17, 2016. [http://www.pedrad.org/LinkClick.aspx?fileticket=3E-HiVxngKs%3d&portalid=5].