Repeatability Over Time of Posture, Radiograph Positioning, and Radiograph Line Drawing: An Analysis of Six Control Groups

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Abstract

Background: There is debate concerning the repeatability of posture over time, radiograph positioning repeatability, and radiograph line drawing reliability. These ideas seem to negate the use of before-and-after spinal radiographic imaging to detect and correct vertebral subluxations.

Objective: To review the results of control groups in 6 clinical control trials with before-and-after radiographic measurements taken days, weeks, months, or years apart to accept or reject the hypothesis that radiographic analysis procedures are not repeatable, reliable, or reproducible.

Data Sources: Six published control groups from original data. Other data were obtained from searches on MEDLINE, CHIROLARS, MANTIS, and CINAHL on radiographic reliability, posture, and positioning.

Results: Comparison of initial and follow-up radiographic data for 6 control groups indicate that measured angles and distances between initial and follow-up radiograph measurements on lateral and anterior to posterior radiographs are not significantly different when utilizing Chiropractic Biophysics radiographic procedures. In 48 out of 50 measurements, the differences between initial and follow-up radiographs are less than 1.5° and 2 mm. These measurements indicate that posture is repeatable, radiographic positioning is repeatable, and radiographic line drawing analysis for spinal displacement is highly reliable. The scientific literature on these topics also indicates the repeatability of posture, radiographic positioning, and radiographic line drawing.

Conclusions: Posture, radiographic positioning, and radiographic line drawing are all very reliable/repeatable. When Chiropractic Biophysics standardized procedures are used, any pre-to-post alignment changes in treatment groups are a result of the treatment procedures applied. These results contradict common claims made by several researchers and clinicians in the indexed literature. Chiropractic radiologic education and publications should reflect the recent literature, provide more support for posture analysis, radiographic positioning, radiographic line drawing analyses, and applications of posture and radiographic procedures for measuring spinal displacement on plain radiographs. (J Manipulative Physiol Ther 2003;26:87-98)

Key Indexing Terms: *Reliability; Repeatability; Posture; Spine; Radiograph; Chiropractic Technique*

Introduction

Postural analysis[1-6] and radiographic line drawing analysis[7-19] have been shown to be highly reliable. However, many arguments that have been developed seem to negate the use of posture and spinal radiographs for diagnosing and treating spinal subluxations and for verifying their correction. This must be a consistent, inherent part of chiropractic radiologic education, because several chiropractic radiologists and clinicians claim 1 or more of the following[20-31]:

1. Radiographic positioning is not repeatable such that variations in positioning simulate subluxation and its consequent correction.
2. Body posture is not a repeatable phenomenon.
3. Radiographic line drawing methods for measuring spinal displacements are not reliable.

For example, Sigler and Howe[21] suggested that at least 4 factors would cause errors in the pre-to-post radiographic analysis of correction of vertebral subluxations on the nasium image: (1) the intraexaminer and interexaminer reliability of radiographic measurement procedures; (2) the repeatability of radiographic procedures, including patient

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positioning; (3) the inherent errors caused by radiographic distortion; and (4) the normal fluctuation of the atlas relative to daily activities or the stability of spinal posture over time. Yochum and Rowe[20] suggested that these variables apply to every area of the spine being evaluated with radiographic imaging.

Recently, we[28] suggested that the items listed by Sigler and Howe[21] are falsely claimed by chiropractic radiologists, and we have debated some of these issues previously.[29,30] According to Haas et al,[29] however, there still is insufficient evidence to claim that the entire radiographic procedure (posture, patient positioning, and radiographic line drawing analysis) is repeatable and reliable.

Given that radiographic analysis of spinal subluxation is taught in the majority of chiropractic colleges and used by many "mainstream" chiropractic techniques, and by approximately 50% of practicing chiropractors, this debate is of great interest to the chiropractic profession.[26,31] Our purpose in this article is to analyze initial and follow-up radiographic data from 6 control groups in clinical trials to evaluate the claims in items 1 through 3 in the previous list, and to compare these findings to existing data in the literature.

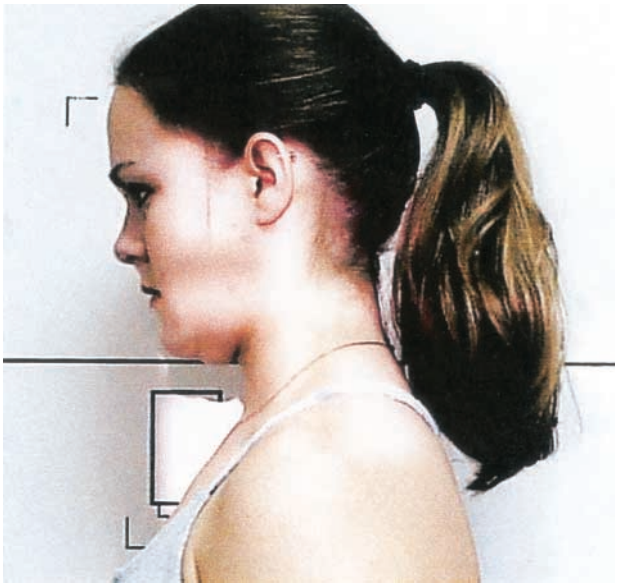

Fig 1. *Lateral cervical radiographic positioning in CBP technique. Thoracic cage positioned perpendicular to grid cabinet. Note that if head flexion is present in the neutral resting posture, it is not artificially changed by leveling the bite line.*

Methods

Since 1994, we have been collecting original radiographic data from 6 control groups for comparison to treatment groups receiving various forms of Chiropractic Biophysics (CBP) treatment methods. Prior to participation in these studies, all subjects were given informed consent forms explaining the details of our projects. These 6 projects were approved by our Internal Review Board. In 3 of the control groups, initial and follow-up lateral cervical radiographs were taken; in one control group, initial and follow-up anterior to posterior (AP) cervical radiographs were collected; another control group consisted of initial and follow-up lateral lumbar radiographs, and still another consisted of initial and follow-up AP lumbar radiographs.

The radiograph positioning procedures taught in CBP technique were followed.[32] All radiographs were taken with the patient standing barefooted, with the feet femur head width apart. For lateral cervical radiographs, the patient's shoulders were positioned perpendicular to the radiographic bucky, and the patient was instructed to close his/her eyes, to flex and extend the head twice, and come to a resting neutral position. This neutral resting posture is that in which the patient perceives his/her head to be looking straight forward. The patient then opens his/her eyes and is instructed to look straight ahead without moving. The patient's abnormal sagittal plane posture is left as is (ie, it is not guided toward an ideal neutral position). The lateral cervical is taken at the standard tube distance of 182.9 cm (72 inches), with the central ray located approximately at the C4 level. Figure 1 depicts the proper positioning of a patient, with slight head flexion in the neutral resting posture.

For the AP cervical radiograph, the patient's median sagittal plane of the thorax is centered relative to the central ray. In other words, the shoulders are parallel with and in the center of the bucky. The central ray is placed at approximately the episternal notch with a 10° to 15° cephalad tube tilt, and with the standard tube distance of 101.6 cm (40 inches). In this manner, the cervical vertebra from C2 down to T6 will appear on the AP cervical. With the thorax centered, the patient is instructed to close his/her eyes, flex and extend his/her skull twice, and assume his/her perceived neutral position. The eyes are then opened, and the patient remains in this position. Any abnormal AP posture of the head relative to the thorax is not removed toward the ideal vertical position. Figure 2 represents the proper positioning for a patient with left lateral head translation relative to the thorax.

For the AP lumbar radiograph, the patient's median sagittal plane of the pelvis is centered relative to the central ray. In other words, the buttocks are parallel with and in the center of the bucky. The central ray is placed at approximately the L3 vertebral level, with the standard tube distance of 101.6 cm (40 inches). In this manner, the pelvis will be centered on the film with the symphysis pubis and S2 tubercle in vertical alignment. With the pelvis centered, the patient is instructed to close his/her eyes, flex and extend his/her head twice, and assume his/her perceived neutral position. The eyes are then opened and the patient remains in this position. Any abnormal AP posture of the thorax relative to the pelvis is not removed toward the ideal vertical

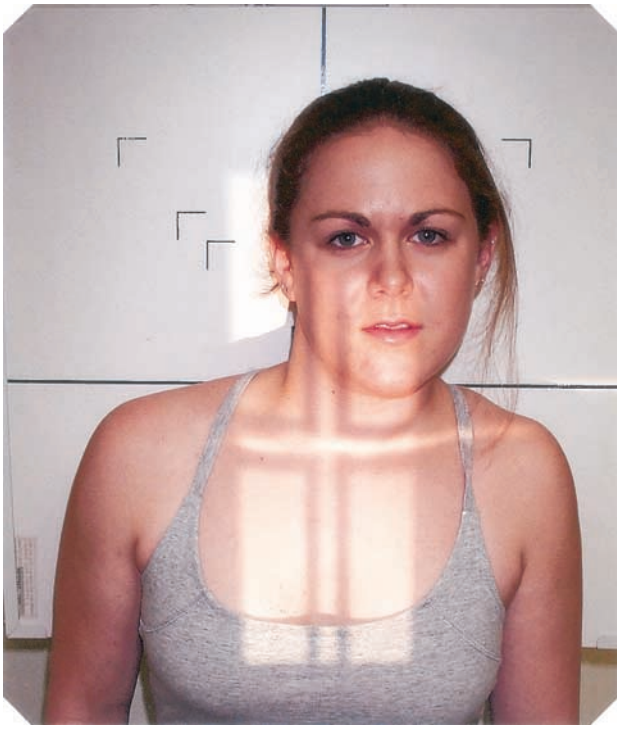

Fig 2. *AP cervical radiographic positioning in CBP technique. Midthoracic cage centered for this radiographic view. Note that if any abnormal head posture is present (in this case, left lateral head translation), it is not artificially reduced to midline.*

Fig 3. *AP lumbar radiographic positioning in CBP technique. Pelvis centered for this radiographic view. Note that if any abnormal thoracic cage posture is present (in this case, left lateral thoracic cage translation), it is not artificially reduced to midline.*

position. Figure 3 represents the proper positioning for a patient with left lateral thoracic translation relative to the pelvis.

For lateral lumbar radiographs, the patient's shoulders and pelvis are positioned perpendicular to the radiograph bucky, the patient is instructed to close his/her eyes, to flex and extend his/her head twice, and come to a resting neutral position. The patient is then instructed to fold his/her arms across the chest in such a manner so as not to displace his/her original sagittal plane posture of the thorax or pelvis. The eyes are then opened and the patient is instructed to look straight ahead without moving. The patient's abnormal sagittal plane lumbar posture is left as is (ie, it is not removed toward an ideal neutral position). The lateral lumbar is taken at the standard tube distance of 101.6 cm (40 inches), with the central ray located approximately at the L4 level. Figure 4 depicts the proper positioning of a patient with thoracic extension relative to the pelvis.

Depending on the study, our control groups are subjects who either did not have pain or had a similar condition to a treatment group. In either case, these subjects elected not to be treated but did volunteer for initial and follow-up examinations. In 1 control group, the initial and follow-up spinal radiographs were performed by the same examiner,[33] whereas in the other 5 groups, the initial radiograph was taken by 1 examiner and the follow-up radiographs were taken by another examiner. These control group subjects came from 2 different chiropractic practices: Five of these control groups were collected at the same office in Elko, Nevada, and the sixth was from the Boston, Massachusetts, metropolitan area. Table 1 presents all group characteristics of these 6 separate control groups.

Lateral Cervical Control Groups

Results for our first lateral cervical control group were originally published in 1994.[33] Thirty volunteer subjects received an initial lateral cervical radiograph and a second lateral cervical radiograph was taken an average of 12 weeks later. Group characteristics were reported; however, no pain questionnaires or scales were obtained. Our second lateral cervical control group comes from a previously published study.[34] This group consisted of 24 patients with chronic neck pain, with initial and follow-up lateral cervical radiographs attained an average of 8.3 mo, with no intervening treatment intervention. Here, subjects were asked to rate the intensity of their perceived pain on a visual analogue scale (VAS) from 0 to 10 (0 = no pain, excellent health, 1, 2, . . . , 10 = excruciating pain and bedridden) at the initial and follow-up evaluations. Our third lateral cervical control group was derived from original data. Here, 33

Fig 4. *Lateral lumbar radiographic positioning in CBP technique. Pelvis is positioned perpendicular to grid cabinet. Note that if any abnormal thoracic cage posture is present in the neutral resting posture (in this case, thoracic extension), it is not artificially changed by positioning toward vertical.*

subjects with chronic NP received an initial and follow-up lateral cervical radiograph, and reported VAS pain scale values. The elapsed time between the 2 radiographs and VAS scores was an average of 8.5 mo.

Lateral Lumbar Control Group

Our lateral lumbar control group data come from a previously published study[35] and have also been presented at a conference proceeding.[36] Here, 30 subjects with chronic lower back pain (LBP) completed an initial and follow-up lateral lumbar radiograph and VAS scale an average of 9.1 months apart.

AP Lumbar Control Group

Our AP lumbar control group was derived from original data. Here, initial and follow-up AP lumbar radiographs and VAS pain scales were collected an average of 8.7 months apart in 23 patients with chronic LBP.

AP Cervical Control Group

Our AP cervical control group was derived from original data. Here, initial and follow-up AP cervical radiographs and VAS pain scales were collected an average of 11.7 months apart in 26 subjects with chronic neck pain.

X-Ray Mensuration Procedures

Examiners analyzed the radiographs with the Harrison posterior tangent method on the lateral cervical views[16] and lateral lumbar views[18] (Fig 5). In an engineering analysis of columns, these tangents are the slopes or first derivatives. Additional angles were measured for the atlas plane line relative to horizontal, Chamberlain's line to horizontal, Ferguson's sacral base angle relative to horizontal, and an angle of pelvic tilt determined by constructing a line from the posterior inferior body corner of S1 to the top of the acetabulum, and comparing this to horizontal. In all but 1 lateral cervical control group,[33] 2-line Cobb angles at end points of curvature were calculated with the computer for the magnitude of cervical and lumbar lordosis.

The Harrison et al[19] modified Risser–Ferguson method was used to analyze both the AP cervical and lumbar views (Fig 6, A and B). Both the CBP posterior tangent and modified Risser–Ferguson methods have high intraexaminer and interexaminer reliability, with small mean absolute differences of observer measurements.[16-19]

Results

Three of our control groups had a lateral cervical radiographic analysis with segmental and global angles. In a 1994 study[33] with a mean follow-up time of 3 months (N = 30 in Table 2), all angles and distances changed less than 1° or 1 mm, except the global absolute rotation angle (ARA) C2–C7, which changed 2.90°. All P values were reported as not statistically significantly different ($P > .05$) except at ARA C2–C7 ($P = .01$). In a 2002 study[34] with a mean follow-up period of approximately 8 months (N = 24 in Table 3), all angles and distances changed less than 1° or 1 mm, and all P values were reported as not statistically significantly different ($P > .05$). In an unpublished study with a follow-up time of approximately 9 months (N = 33 in Table 4), all angles and distances changed less than 1.40° or 1.9 mm, and all P values were reported as not statistically significantly different ($P > .05$).

One of our control groups consisted of segmental and global analysis of initial and follow-up lateral lumbar radiographs, with a mean follow-up time of approximately 9 months (Table 5). [35] All angles and distances changed less than 1° or 1 mm, and all P values were not statistically significantly different ($P > .05$).

Another control group consisted of AP cervical radiographic analysis (N = 23 in Table 6) and still another consisted of AP lumbar radiographic analysis (N = 26 in Table 7). The mean follow-up times were 11.7 months and 8.7 months, respectively. All angles and distances changed less than 1° or 1 mm, and all P values were reported as not statistically significantly different ($P > .05$), except the

Table 1. *Characteristics of 6 control groups (mean ± SD)*

Study	N	Sex: F/M	Age (y)	Height (cm)	Weight (kg)	VAS* Initial	VAS* Follow-up	Follow-up period
Lateral Cervical #1†	30	17/13	34.8 ± 11.1	NR	NR	NR	NR	3 mo
Lateral Cervical #2	24	13/11	35.1 ± 11.5	172.4 ± 7.3	74.5 ± 9.5	3.6 ± 2.1	3.8 ± 1.8	8.3 mo
Lateral Cervical #3	33	14/19	37.0 ± 11.1	174.1 ± 8.2	85.2 ± 19.5	3.5 ± 2.0	3.4 ± 1.8	8.5 mo
Lateral Lumbar	30	12/18	39.4 ± 13.7	173.4 ± 9.2	82.5 ± 16.3	4.2 ± 2.0	3.7 ± 2.1	9.1 mo
AP Lumbar	23	6/17	39.7 ± 11.2	173.6 ± 9.0	85.7 ± 17.6	3.9 ± 2.1	3.8 ± 2.0	8.7 mo
AP Cervical	26	8/18	39.5 ± 10.1	173.7 ± 7.8	85.8 ± 15.8	3.5 ± 2.0	3.6 ± 2.1	11.7 mo

NR, Not reported.
*VAS: 0 = no symptoms, no limitations to daily living; 1, 2, . . . , 10 = severe pain and bedridden.
†Subjects were from Boston Metropolitan area; the other 5 groups were from Elko, Nevada.

lateral translation distance of T12 to S2, which worsened by 2.4 mm at long-term follow-up, as shown in Table 7.

Discussion

For initial and follow-up radiologic examinations of control groups, our data in Tables 2 through 7 show nearly identical measurement values. These radiographic measurements can only be nearly identical if (1) radiographic positioning is repeatable, (2) posture is stable (identical) over time, and (3) radiographic line drawing analysis is reliable.

Our data are in contrast to the opinions professed by several authors in the literature. To identify the origin for the opinions that radiographic positioning is not reproducible, posture is not repeatable, and radiographic line drawing is unreliable, we searched the peer-reviewed, indexed literature, and radiology textbooks for information on the topic of chiropractic radiologic analysis of subluxations. Multiple articles and textbooks were identified in the chiropractic literature,[20-29] which promulgated the opinion that chiropractic radiographic procedures are not reproducible to the extent needed for identification of subluxation correction. However, none of these sources adequately addressed the issue at hand. These authors either offered their own opinion as supporting evidence for the nonreproducibility of radiographic analysis or referenced another source that offered its author(s) own opinions, with no supporting data as evidence. This type of "scientific" evidence, termed expert opinion, is based largely on the reputation or experience of the author(s). According to Stein,[37] this is one of the fallacies of scientific evidence. Stein states, "It is fallacious for a researcher to accept the opinions of a respected scientist on the sole basis of his reputation without any supporting data."

Radiographic Positioning Repeatability

Instead of accepting the conventional wisdom of chiropractic radiologic education, which is in contrast to our

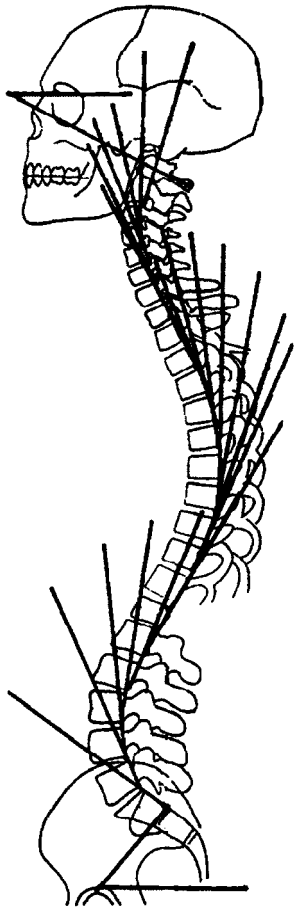

Fig 5. *The Harrison Posterior Tangent Method is applied to lateral radiographs by drawing intersecting lines on posterior vertebral body margins. These lines create relative rotation (segmental) angles and absolute rotation (global) angles. In addition, the inclination of C1 and S1 is compared to horizontal, an angle of pelvic tilt from S1 to acetabulum to horizontal, and horizontal translations of T12 to S1, and C1 to T1, are determined.*

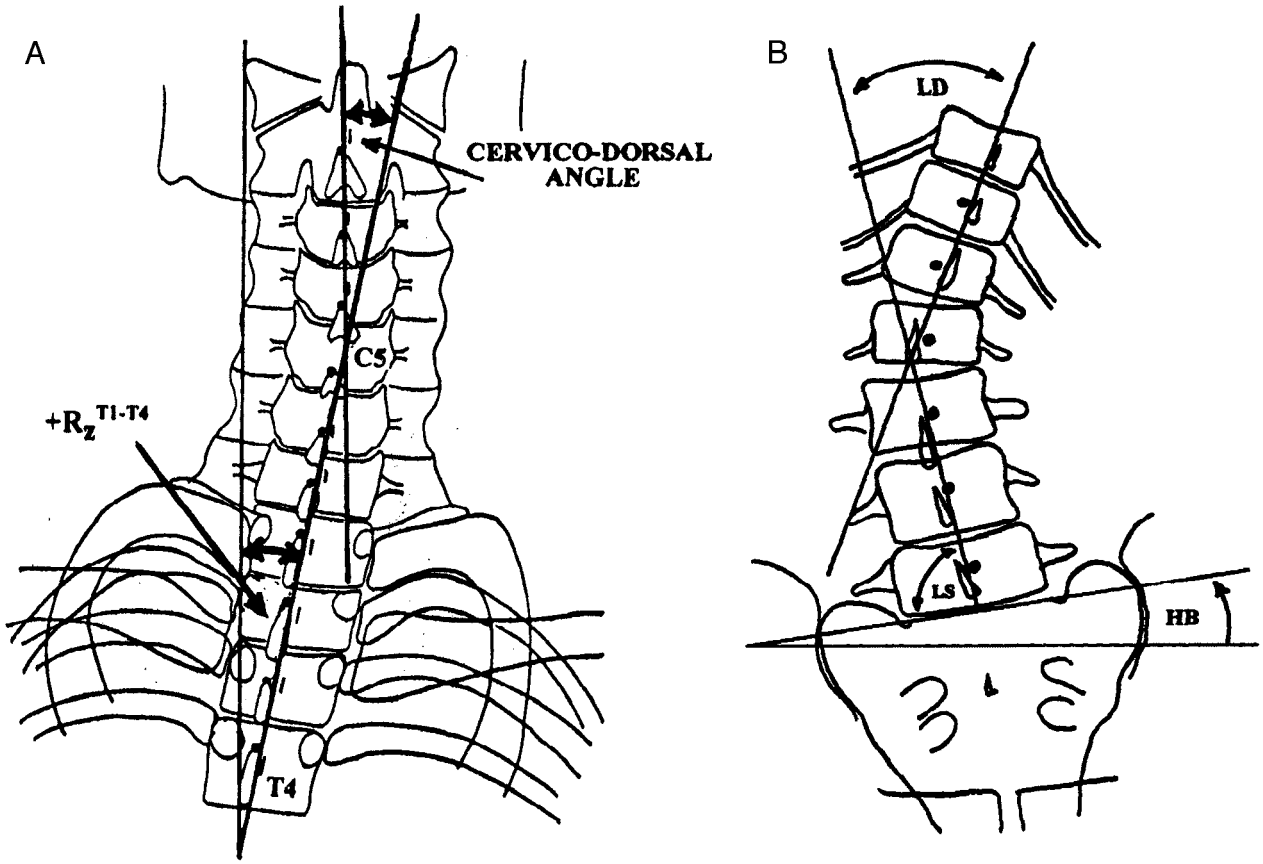

Fig 6. *The Harrison Modified Risser–Ferguson method is used on both the AP cervical (**A**) and the AP lumbar (**B**) radiographs. Any deviation from true vertical is measured in degrees. The horizontal translation of T12 to S2, and C2 to T3 or T4, is measured in millimeters from vertical. The sacral base is compared to horizontal.*

Table 2. *Lateral cervical control group #1 average radiographic measurement comparison, follow-up at 3 mo*[33]

Variable	Preradiographic Mean, SD	Postradiographic Mean, SD	Change	*P**
$Tz^{C2\text{-}C7}$ (mm)	20.9 ± 9.6	20.4 ± 10.4	0.5	>0.05
C1-Horizontal	−17.0° ± 7.3°	−17.8° ± 7.6°	−0.8°	>0.05
RRA C2-C3	−4.4° ± 5.0°	−5.2° ± 4.7°	−0.8°	>0.05
RRA C3-C4	−3.6° ± 5.4°	−3.6° ± 4.1°	0.04°	>0.05
RRA C4-C5	−1.6° ± 5.2°	−2.5° ± 5.1°	−0.9°	>0.05
RRA C5-C6	−1.6° ± 5.8°	−2.2° ± 4.8°	−0.6°	>0.05
RRA C6-C7	−7.0° ± 5.3°	−7.4° ± 5.7°	−0.4°	>0.05
ARA C2-C7	−18.2° ± 13.5°	−21.1° ± 14.5°	−2.9°	0.01

N = 30.
Tz, horizontal distance of C2 posterior-superior body corner to posterior-inferior of C7; *RRA*, segmental angle formed by posterior vertebral body tangents; *ARA*, total curve angle from C2 to C7 formed by posterior vertebral body tangents.
*Two-sided paired *t* test.

control group data sets, we performed a MEDLINE search, seeking information from any health care discipline documenting the reliability and repeatability of spinal radiographic positioning in control groups or treatment group subjects. This search revealed 20 such manuscripts.[1,2,13,38-54] Twelve of these manuscripts deal with lateral cervical radiographic analysis,[1,38-48] 2 deal with the lateral lumbar spine,[49,50] 4 concern the lateral thoracic kyphosis,[2,49-51] 3 concern the AP cervical and 1 nasium radiograph,[46,47,52,53] and 2 concern the AP lumbopelvic radiograph.[13,54]

Lateral Cervical and Skull Radiographs

Multiple orthodontic researchers have demonstrated reproducibility of patient placement and repeatability of sag-

Table 3. *Lateral cervical control group #2 average radiographic measurement comparisons*[34]

Variable	Preradiographic Mean, SD	Postradiographic Mean, SD	Change	*P**
Tz^{C1-T1} (mm)	21.7 ± 12.7	21.0 ± 12.5	0.8	>0.05
Tz^{C2-C7} (mm)	21.3 ± 11.1	21.0 ± 10.2	0.4	>0.05
C1-Horizontal	−16.6° ± 6.5°	−17.3° ± 7.7°	0.7°	>0.05
RRA C2-C3	−4.8° ± 5.9°	−4.8° ± 4.8°	0.1°	>0.05
RRA C3-C4	−1.6° ± 4.7°	−2.1° ± 5.6°	0.5°	>0.05
RRA C4-C5	−0.8° ± 5.7°	−1.1° ± 4.6°	0.4°	>0.05
RRA C5-C6	−0.4° ± 4.5°	0.6° ± 4.1°	−1.0°	>0.05
RRA C6-C7	−2.3° ± 5.8°	−3.4° ± 6.4°	1.1°	>0.05
ARA C2-C7	−9.9° ± 10.8°	−10.8° ± 9.0°	0.9°	>0.05
Cobb C1-C7	−37.9° ± 12.0°	−37.7° ± 10.2°	−0.2°	>0.05
Cobb C2-C7	−6.1° ± 13.5°	−5.6° ± 10.4°	−0.5°	>0.05
Chamberlain-Horizontal	−1.7° ± 6.0°	−2.7° ± 6.5°	1.0°	>0.05

N = 24.
Average time between first and follow-up radiographs is 8.1 months. Negative sign in RRA/ARA/Cobb indicates extension.
Tz, Horizontal distance of C1 posterior-superior lateral mass to posterior-inferior of T1 or horizontal distance of C2 posterior-superior body corner to posterior-inferior of C7; *RRA*, segmental angle formed by posterior vertebral body tangents; *ARA*, total curve angle from C2 from to C7 formed by posterior vertebral body tangents; *Cobb angle C1-C7*, line through C1 arches to inferior endplate of C7; *Cobb angle C2-C7*, line on inferior endplate of C2 to inferior endplate of C7; *Chamberlain-Horizontal*, posterior hard palate to posterior foramen magnum to horizontal.
*Two-sided paired *t* test.

Table 4. *Lateral cervical control group #3 average radiographic measurement comparisons*

Variable	Preradiographic Mean, SD	Postradiographic Mean, SD	Change	*P**
Tz^{C1-T1} (mm)	23.3 ± 13.5	21.4 ± 13.7	1.8	>0.05
Tz^{C2-C7} (mm)	23.1 ± 13.5	22.4 ± 11.6	0.8	>0.05
C1-Horizontal	−15.1° ± 6.5°	−16.0° ± 7.6°	0.9°	>0.05
RRA C2-C3	−4.5° ± 5.7°	−4.3° ± 4.6°	−0.2°	>0.05
RRA C3-C4	−1.6° ± 4.6°	−2.0° ± 5.3°	0.4°	>0.05
RRA C4-C5	−1.1° ± 5.6°	−1.5° ± 4.6°	0.5°	>0.05
RRA C5-C6	−0.7° ± 4.7°	0.1° ± 4.3°	−0.8°	>0.05
RRA C6-C7	−2.4° ± 5.5°	−3.3° ± 5.8°	1.0°	>0.05
ARA C2-C7	−10.2° ± 10.9°	−11.1° ± 9.0°	0.9°	>0.05
Cobb C1-C7	−37.1° ± 11.1°	−36.9° ± 9.9°	−0.2°	>0.05
Cobb C2-C7	−5.6° ± 13.0°	−5.8° ± 10.1°	−0.2°	>0.05
Chamberlain-Horizontal	−1.6° ± 5.6°	−2.9° ± 5.7°	1.3°	>0.05

N = 33.
Negative sign in RRA/ARA/Cobb indicates extension.
Tz, Horizontal distance of C1 posterior-superior lateral mass to posterior-inferior of T1 or horizontal distance of C2 posterior-superior body corner to posterior-inferior of C7; *RRA*, segmental angle formed by posterior vertebral body tangents; *ARA*, total curve angle from C2 from to C7 formed by posterior vertebral body tangents; *Cobb angle C1-C7*, line through C1 arches to inferior endplate of C7; *Cobb angle C2-C7*, line on inferior endplate of C2 to inferior endplate of C7; *Chamberlain-Horizontal*, posterior hard palate to posterior foramen magnum to horizontal.
*Two-sided paired *t* test.

ittal plane natural head posture (NHP) radiographs over time.[1,38-46] Hellsing et al[38] performed a reproducibility study of cephalometric radiographs of 14 adults over a period of 8 months. Two exposures were taken in each series for each patient. The first was without the use of stabilizing ear rods, and the second was with the ear rods. A digitizer was used to measure 13 angles and 12 lines relative to horizontal/vertical. After an average period of 8 months, it was concluded that no significant differences existed on the follow-up films.

Foster et al[39] performed a repeatability study of 9 subjects with follow-up radiographs performed after an interval of at least 2 weeks. Head repositioning was analyzed with the use of 4 lines relative to true vertical. The mean error for the angles measured ranged from 3.0° to 4.8°. However, the digitizing measurements revealed a method error ranging from 0.86° to 4.9°, indicating that the radiographic positioning errors were within the mean error of measurement method.

In a retrospective analysis, Luyk et al[40] assessed the reproducibility of the NHP with more radiographs per patient (mean = 4.3) than previous prospective studies. Eighteen patients were analyzed in the NHP in a series of films

Table 5. *Lateral Lumbar Control Group average radiographic measurement comparisons*[35]

Variable	Preradiographic Mean, SD	Postradiographic Mean, SD	Change	*P**
Tz^{T12-S1} (mm)	−15.6 ± 16.43	−15.6 ± 14.75	0.05	>0.05
RRA T12-L1	−0.03° ± 3.43°	−0.55° ± 2.44°	0.52°	>0.05
RRA L1-L2	−2.02° ± 4.16°	−1.72° ± 4.37°	−0.30°	>0.05
RRA L2-L3	−7.95° ± 3.91°	−6.96° ± 3.75°	−0.99°	>0.05
RRA L3-L4	−10.10° ± 4.34°	−10.55° ± 3.96°	−0.45°	>0.05
RRA L4-L5	−16.65° ± 6.19°	−16.66° ± 6.23°	0.01°	>0.05
RRA L5-S1	−30.56° ± 8.16°	−29.93° ± 8.07°	−0.63°	>0.05
ARA L1-L5	−36.72° ± 12.8°	−35.87° ± 12.3°	−0.85°	>0.05
Cobb T12-S1	−59.38° ± 10.4°	−59.19° ± 9.64°	−0.19°	>0.05
Ferguson	37.08° ± 6.65°	37.07° ± 7.16°	−0.01°	>0.05
Pelvic tilt	42.06° ± 9.04°	41.94° ± 8.04°	−0.12°	>0.05

N = 30.
Negative sign in RRA/ARA/Cobb indicates extension.
Tz, Horizontal distance of T12 posterior-inferior body corner to posterior-inferior of S1; *RRA*, segmental angle formed by posterior vertebral body tangents; *ARA*, total curve angle from L1 form to L5 formed by posterior vertebral body tangents; *Cobb angle*, inferior endplate of T12 to superior surface of sacrum; *Pelvic tilt*, arcuate angle from posterior-inferior S1 to top of acetabulum to horizontal.
*Two-sided paired *t* test.

Table 6. *AP Cervical Control Group average radiographic measurement comparison*

Variable	Preradiographic Mean, SD	Postradiographic Mean, SD	Change	*P**
Tx^{C2-T3} (mm)	8.1 ± 5.7	8.8 ± 5.2	−0.7	0.05
CD Angle (°)	4.9 ± 3.4	5.0 ± 3.9	−0.1	0.05
Rz Angle (°)	3.4 ± .2	3.8 ± 3.6	−0.4	0.05

N = 26.
Tx, Lateral distance of C2 from a vertical line through T3; *CD*, cervicodorsal angle formed at midneck by best-fits lines through centroids; *Rz*, lateral bending of line through centroids of T1-T3 from vertical.
*Two-sided paired *t* test.

Table 7. *AP Lumbar Control Group Average radiographic measurement comparison*

Variable	Preradiographic Mean, SD	Postradiographic Mean, SD	Change	*P**
Tx^{T12-S2} (mm)	7.2 ± 6.2	9.6 ± 7.3	−2.4	= 0.011
LD Angle (°)	5.0 ± 2.0	4.7 ± 2.0	0.3	>0.05
LS Angle (°)	2.9 ± 1.7	3.1 ± 2.1	−0.2	>0.05
HB Angle (°)	2.8 ± 1.5	2.3 ± 1.4	0.5	>0.05

N = 23.
Tx, Lateral distance of T12 from a vertical line through S2 tubercle; *LD*, lumbodorsal angle, formed at midlumbar spine by best-fit lines through centroids; *LS*, lumbosacral angle, formed by centroidal best-fit lines in lower lumbar as it intersects a line on the sacral base; *HB*, horizontal base angle formed by line on sacral base compared to horizontal.
*Two-sided paired *t* test.

taken over an average of a 3-year period. A control group that comprised 18 patients (where a cephalostat with ear rods for radiography in orthodontic planning was utilized) had at least 3 cephalostat films taken over a period of 3 years. The reproducibility varied by a mean of only 5.2° for the angle measured. Their results showed no significant differences ($P > .7$) between the 2 groups or the examiners. Thus, the NHP was equally as reproducible over time compared to the subjects for which the cephalostat was used for radiographs. Houston et al[41] obtained initial and repeat cephalostat radiographs of 24 patients on the same day. Radiographic positioning errors were found to be small and below the SEM system. Cooke and Wei[42,43] and Peng and Cooke[44] performed a series of NHP repeatability radiographs with short and longitudinal follow-up. In the first of their series,[42] 217 children were randomly allocated to 6 different radiographic positioning groups. Repeat radiographs were taken at different intervals between the groups: immediate (4-10 minutes) repeat radiographs, delayed (1-2 hours) repeat radiographs, and months (3-6 months) later. In one of their groups, in which a self-balance position with a mirror was used on the initial and the NHP without a mirror on the repeat, significant differences were detected at $P < .01$; however, the maximum error was only 2.9°. In 5 of the 6 groups, no significant differences were found between the initial and repeat radiographs. In both a 5-year and 15-year follow up on these subjects, similar repositioning errors were found on the repeated radiographs. Peng and Cooke[44] stated, "The 15 year head posture reproducibility therefore compared well to the original repeat recordings after 5-10 minutes and the later repeats after 5 years."

Siersbaek-Nielsen and Solow[45] took initial and repeat lateral cephalometric films of 30 subjects between the ages of 6 and 15 years. The radiographs were taken 1 and 35 days apart; 21 radiographs were made by the same examiner and 9 were taken by different examiners for the initial and repeat radiographs. All measured values showed differences of

3.4° or less, and no differences were found between examiners, age groups, or time interval between radiographs. They stated, "We found no significant difference between the three different operators in spite of their different education and practical experience."

Sandham[1] compared repeat lateral cervical radiographs of 12 subjects with at least 1 hour between the first and second radiographs. Six different measures of cervical spine and head position were calculated with their respective mean values, SDs, SEs, and method errors, with the statistical *t* test used for comparisons. No statistically significant differences were noted among any of the variables between the first and repeat lateral cervical radiographs. Sandham concluded, "The study demonstrates that reproducible head posture films can be reliably obtained by general radiographers in x-ray departments as part of routine and varied daily work, and with simple instruction for positioning."

In the chiropractic and orthopedic literature, we found 2 articles on lateral cervical radiographic repositioning. Jackson et al[47] investigated the reliability of Pettibon patient positioning procedures in the analysis of lateral cervical radiographs. Two series of radiographs of 38 patients were taken 30 minutes to 4 hours apart. Using a reliable radiographic marking procedure,[10] the authors demonstrated repositioning reliability with an SEM of less than 1° for all measurements reported. On repeated lateral cervical radiographs of 159 subjects, with an average interval of 10 years, Gore[48] found no statistically significant differences between repeat radiographs in the means and standard deviations for posterior body tangent lines between C2 and C7.

Lateral Thoracic Radiographs

Singer et al[51]compared 22 pairs of in vivo and postmortem lateral thoracic films. The time difference between the films ranged from 3 days to 77 months. No statistically significant differences were found in the magnitude of thoracic kyphosis using the Cobb method and a computer-assisted curvature measurement. Milne and Williamson[2] reported no significant change in radiographically determined thoracic kyphosis measurements for initial and average 5-year follow-up in 261 elderly subjects. Jackson et al[49] took initial and follow-up lateral full-spine radiographs in 20 volunteers and 20 patients with LBP taken 66 months and 2 weeks apart, respectively. Very little variation in the thoracic kyphosis from T1 to T12 was found between the first and follow-up radiographs with ranked correlation coefficients of $r = 0.81$ for volunteers and $r = 0.79$ for patients. Using a statistical model with Cartesian coordinates representing the path of the vertebral bodies of the thoracic and lumbar spine in the sagittal plane, Beck and Killus[50] stated that "several x-rays of the same individuals furnished reproducible results, even though they were taken years apart."

Lateral Lumbar Radiographs

In at least 2 studies, repeat radiographs of the lateral lumbar spine in the same subject have been performed.[49,50] Jackson et al[49] reported ranked correlation coefficients of .93 to .96 for lumbar lordotic measurements for initial and follow-up radiographs of 20 volunteers and 20 patients with LBP. According to Stagnara et al,[55] "For subjects undergoing clinical and x-ray examinations at intervals of five to ten years, and where no growth or pathologic deformation factors are to be taken into to account, the clinical and x-ray measurements of kyphosis and lordosis are remarkably constant to within a few degrees, provided the position is clearly stipulated."

AP Cervical and Skull Radiographs

Rochester and Owens[52] found that the average amount of patient to tube/film head axial rotation was 0.56° in 20 randomly pulled nasium films. Furthermore, they calculated that this amount of patient placement error for the nasium radiograph would only produce an average artifact in the atlas laterality of 0.21°. They concluded that "repositioning the patient for the post radiographic exam would not introduce significant error into the x-ray analysis." Jackson et al[47] obtained initial and repeated seated nasium radiographs in 38 subjects within 4 h after receiving a sham adjustment. All measures were within 1.0° between initial and repeat radiographs; no statistically significant differences were found. Huggare[53] performed a study analyzing NHP on posterior to anterior skull radiographs of 22 dental students. Two radiographs were obtained of each subject at a 1-week interval. Craniovertical, craniocervical, and cervicohorizontal angles were measured. The reproducibility (method error) of the craniovertical, craniocervical, and cervicohorizontal angles were 1.15°, 0.93°, and 1.45°, respectively. Huggare[53] concluded that the "frontal head position is more accurately reproducible than the sagittal head position."

AP Pelvis Radiographs

Plaugher et al[13] studied the reliability of patient positioning utilizing AP pelvic radiography. This study had 2 follow-up periods. Twenty volunteers had repeat radiography after approximately 1 hour, and 17 subjects received follow-up radiography after 18 days. The authors chose Gonstead technique line drawing procedures for analysis of the pelvis and leg length discrepancies. In the first group, the results showed no statistically significant differences ($P > .05$) between the 2 radiographs at 1 hour apart. The second group showed similar results at an average of 18 days ($P > .05$). In 105 patients with chronic LBP, Friberg[54] retook pelvic radiographs to analyze the consistency of anatomic leg length inequality and pelvic rotation around the longitudinal axis. Radiographs were repeated after an interval of 2 weeks to 3 years. The mean error between repeat radiographs was 0.7 mm for anatomic leg length; in 46 of 105 subjects, an analysis of pelvic rotation ranged from 0° to 3.0°, with a mean of 0.9°.

Posture Repeatability

The reproducibility of neutral, standing upright posture has been studied and shown to be highly repeatable, with a method error of 1.0° to 3.0° in both the sagittal and coronal planes.[1,3-6,30] Even though we did not measure neutral standing posture with photographs or a posture digitizer in our control groups, we can still directly claim posture repeatability from our data, using the concepts of main motion and coupled motion.

Main motion and coupled motion have been defined.[56] Main motion is the postural movement (eg, head lateral bending); this main motion is always found in the segmental motions (the cervical segments laterally bend when the head does); and the additional observed 5 cervical segmental motions are termed coupled motions (axial rotation, flexion/extension, lateral translation, forward/backward translation, and vertical translation). The majority of postural main motions have been studied in the literature, and their spinal coupled motions are well known.[57-61] If posture had changed in any of our control groups, then spinal coupling and the projected images of spinal coupling would have changed. Because the lateral and AP pre- and postradiographic measurements in our control groups were not statistically different and generally had differences in angles and distances of less than 1.0° and 1 mm, using a common tautology in logic $[(p \Rightarrow q) \Leftrightarrow (\sim q \Rightarrow \sim p)]$, we can claim that posture did not change in our control groups.

Radiographic Line Drawing Reliability

In 2 previous reviews of the literature, we discussed the fact that the reliability of several types of radiographic line drawing analysis has been shown to be in the good to high range and is therefore adequate for research and clinical uses.[28,30] In the current study, the Harrison Posterior Tangent method was used for analysis of lateral cervical and lumbar radiographs, whereas the Harrison modified Risser–Ferguson method was used to assess the AP cervical and AP lumbar spinal radiographs. Importantly, both the Harrison Posterior Tangent[16-18] and modified Risser–Ferguson[19] methods have been shown to be very accurate and reliable for both interobserver and intraobserver measures, with mean absolute value of observer errors less than 3.0° for angles and 2 mm for distances.

However, with the use of the same tautology discussed in the section on posture repeatability, $[(p \Rightarrow q) \Leftrightarrow (\sim q \Rightarrow \sim p)]$, it should be apparent that our line drawing methods must be reliable in order for the measurements of spinal displacement to be nearly identical on the initial and follow-up radiographs.

Study Limitations

For our study's control groups, we used the radiographic positioning procedures taught by the CBP technique for both the initial and follow-up radiographs of each subject. Therefore, our data showing the repeatability of spinal radiographic positioning in our control groups only applies to CBP procedures. However, we identified 20 other manuscripts in the literature in which the Gonstead technique for AP pelvis positioning, general positioning procedures for AP pelvis radiographs for femoral height and pelvic rotation, full spine lateral positioning, lateral thoracic positioning, lateral cervical positioning and NHP, and AP nasium positioning procedures were all found to be repeatable.[1,2,13,38-54]

In contrast, in looking at an opposing opinion from Haas et al,[29] the above information does not adequately demonstrate the repeatability of spinal radiographic positioning procedures. Haas et al[29] suggested that the radiographic positioning procedure be subjected to intra- and interexaminer reliability, where (presumably) at least 2 to 3 examiners would position and take radiographs of each subject at least twice. Although from a purely scientific perspective, we agree with the Haas et al[29] comment, we also know that this kind of study will probably never be performed because of ethical concerns with the use of human subjects for research purposes. Until such a study is performed and refutes our findings, our data and literature review demonstrate that, indeed, radiographic positioning is repeatable. In addition, looking at the flexion in the neutral resting posture in Figure 1 concerning the lateral cervical view, it might be thought that the head should be extended to level the bite line before exposing the radiograph. It is a common belief in radiology that any head nodding (head flexion/extension) present on a prelateral and postlateral cervical will negate any apparent improved lordotic measurements. Recently, we have shown that this common belief is false.[62] An average of 14° head extension on a second lateral cervical resulted in very small cervical curve changes between C2 and C7 in subjects with neck pain, with cervical kyphosis and slight head flexion on their initial lateral cervical radiograph.[62]

Finally, a concern not addressed in this article is the issue of validity, although reliable, measured displacements on spinal radiographs may not be valid. Previously, we have discussed the validity concerns with spinal radiograph assessment in both our original articles[57,58,63] and texts.[32] Due to the symmetry of the human spine about the median sagittal plane, the AP radiographic views are more susceptible to projection/distortion of vertebral movement. We therefore recommend that the 2-dimensional projected coupling patterns always be compared to the 3-dimensional spinal postures for a validity analysis. On the other hand, the spine is not symmetric about the coronal plane, and the movements (flexion/extension, forward/backward translation, vertical translation) of the spine in this plane are perpendicular to the radiographic source. The lateral view, accordingly, is not susceptible to the same projection/distortion problems as the AP view. In fact, it has been shown that a minimum of 150° of axial rotation and/or lateral bending must be present before the measurement of spinal lordosis on radiograph is affected compared to the neutral position.[64]

Conclusions

In data from control groups in 6 CBP clinical control trials, only 2 radiographic measurements out of 50 angles and distances showed a statistically significant difference (ARA C2-C7 improved 2.9° in Table 2, Tx^{T12-S2} worsened by 2.4 mm in Table 7). Otherwise, all differences of angles and distances were less than 1.5° and 2 mm. This control group data indicates that posture is stable over time, radiographic positioning is repeatable, and the CBP radiographic line drawing methods are reliable.

Although opponents to radiographic analysis have only personal opinion against repeatability of radiographic procedures, besides the data presented here and our own 10 radiographic analysis reliability studies published in the Index Medicus, review of the literature provides a plethora of reliability studies on posture stability, radiographic positioning, and radiographic geometric line drawings of multiple types.

It is time for chiropractic college faculty, clinicians, and chiropractic radiologists to recognize/admit to the repeatability/reliability of standing posture, radiographic positioning, and radiographic geometric line drawing analyses.

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