VIII. Reliability of Geometric Line Drawing Radiographic Analysis

RECOMMENDATION

Radiographic line drawing procedures for spinal and lower extremity positions have been subjected to a large volume of inter and intra examiner reliability studies. The overwhelming majority of these studies have found that examiner reliability is in the excellent range and thus can be used for the clinical evaluation of spinal subluxation by chiropractic clinicians.

Supporting Evidence: Reliability Studies Class 1 and 2.

PCCRP Evidence Grade: Reliability Studies = a and b.

Introduction

Even though there has been a plethora of inter and intra-examiner reliability studies performed on geometric line drawing analysis on radiographs of all regions of the spine and extremities,[1-148] some Chiropractic radiologists and academics still continue to claim that "there is little or no evidence to support reliability of x-ray line drawing analysis".[149] With nearly 150 published papers on this topic, geometric x-ray line drawing of spinal displacements is one of the most studied topics in the indexed literature.

In a recent Chiropractic text, regarding x-ray line drawing, Peterson and Hsu[150] stated, "*…attempts to evaluate the reliability (ability to obtain the same measurements on more than one occasion or between different examiners) have given conflicting results.*" In support of this statement, Peterson and Hsu[150] provide 3 references. The first of these references is from Haas et al[149]; this was not a review of the relevant reliability studies but a dissent largely based on Class V evidence. Importantly, this opinion article[149] was subsequently thoroughly critiqued.[151] The second reference provided by Peterson and Hsu[150] appears to be a student paper written for a non-post graduate degree and is rather odd to be used as a scientific source for such a statement. The third study cited by Peterson and Hsu[150] in their attempt to curtail the reliability of x-ray line drawing procedures is a study on 'visual' estimation of lumbar lordosis and did not utilize line drawing methods whatsoever.[152] Interestingly, this article[152] was subsequently thoroughly critiqued.[153]

The above scientific facade of references to support the agenda that x-ray line drawing in chiropractic is not reliable or at best has questionable reliability is not an isolated event in chiropractic literature. For example, in a literature review of subluxation assessment methods, Owens[154] stated that the reliability of lumbar x-ray line drawing methods is 'poor to nonexistent'. In support Owens[154] (like Peterson and Hsu[150]) used the Haas et al[149] study and also a study by French et al.[155] Astonishingly, the study by French et al[155] did not assess lumbar line drawing methods and, in fact, no measurements were made on x-rays what so ever!

As mentioned in an earlier section, these 'pseudo-scientific' radiography articles and chapters, written by a minority group of publishing DACBRs and academics, are used by Managed Care Organizations (MCO's) (such a ACN and ASHN)[156] to deny coverage for radiology services for patients seeking chiropractic care. Thus, we can only conclude that these radiology articles and texts are linked, in no small way, to MCO's creating a situation where the chiropractic clinician is removed from the patient treatment decision making process such that costs can be 'controlled' and profits can be 'maximized'.[157]

The shear number and quality of studies demonstrating sufficient reliability[1-148] of geometric line drawing analysis on radiographs of all regions by Chiropractors, Medical Doctors, and Orthodontists makes the above DACBR and academic statement concerning x-ray line drawing reliability quite absurd.

In an effort to dispel the generalized Class V (expert opinion) evidence that radiographic line drawing procedures are unreliable, the current panel decided to provide tables of reliability studies in each region of the spine and pelvic area in this section. Another reason for our separate tables of each region and each type of study (AP, lateral, flexion/extension) is to benefit the reader's future ease of finding the appropriate study for any area of radiographic investigation from the approximately 148 published studies on this topic.

The arrangement of the following Tables (1-12) is by region and by view: Head, AP Cervical and nasium, lateral cervical, cervical flexion/extension, AP thoracic and AP full spine, lateral thoracic, AP lumbar and Ferguson, lateral lumbar, lumbar flexion/extension, lateral full spine, AP and lateral pelvis, and lower extremity.

Summary

This volume of literature determining the reliability of x-ray line drawing procedures for spinal, pelvic, and extremity alignment, is contradictory to the Class V evidence but forth by a subgroup of Chiropractic Radiologists and some chiropractic academics in their attempt to discredit chiropractic radiology measurement of spinal subluxation.

Table 1. Head Orthodontic X-rays Reliability

Author, Year	Films, Examiners	Findings
Chen et al, 2000	Lateral head & Neck 10 films, 7 residents	Inter-observer error on digital images was > than on radiographs; significant differences only in 4/19 landmarks
Chen YJ et al, 2004	Lateral head & Neck 10 films, 7 examiners	Radiographs & digitized images: Differences in 21 of the 27 cephalometric items were less than two units of measurement (mm or degree). Inter-observer errors on digitized images are comparable to radiographs and are clinically acceptable
Gliddon MJ et al, 2006	8 films, 2 examiners	Error of both manual & LS-5 methods was 0.5 mm. The LS-5 method had its advantage because it could be automated by computer.
Hermann NV et al, 2001	40 films, 1 examiner	Error due to landmark digitization determined by Dahlberg's formula was 0.8 mm for linear variables & 1.6 degrees for angular variables.
Wah PL et al, 1995	60 films, 1 examiner	No significant differences in landmark location & measurement between the orthodontic & surgical patient groups. Extreme variations in skeletal morphology do not affect accuracy of cephalometric evaluation.

Table 2. AP Cervical (& Nasium) Reliability Studies

Author, Year	Films, Examiners	Findings
Addington EA, 1986 and 1987	Blair technique nasium, condyle	80-90% agreement between examiners measurmenet of upper cervical subluxation on the Blair technique views.
Harrison DE et al, 2002	30 films, 3 examiners.	8 Intra- & Inter- examiner ICCs > 0.88. observer error was in interval (0.8º,3.2º) for angles and <1 mm for distances.
Jackson BL et al, 1987	30 films, 6 examiners.	Reliability (stability over time) for the practitioners is very good. Reliability (equivalence over experts) across the practitioners is very good. The standard error of measurement for 6 examiners was 0.41° for the upper angle and .61° for the lower angle.
Jackson et al, 1988	38 nasiums, 3 examiners, 2 occasions.	Inter- & Intra-examiner Pearson's r > 0.92. Standard error of measurement for Upper angles (UA) < 0.5º and SEM for lower angles (LA) < 0.8 º.
Jackson et al.,2000	2x38 nasium.	After sham adjustment: All measures ≤ 1.0° between 38 sets of pre-post nasiums.
Janik TJ et al, 2001	30 films, 3 examiners	For axial rotation, the intra-class ICCs ≥ 0.78, &the inter-class ICCs ≥ 0.67. For lateral flexions (Rz) of C3-T3, all intra-class and inter-class ICCs > 0.87.
Owens EF Jr, 1992	AP Nasium & Vertex Review	Reliability studies report inter- and intra-examiner reliability are sufficient to measure lateral and rotational displacements of C1 to within ± 1º on the Nasium x-ray.
Rochester RP, Owens EF, 1996	20 films, 1 examiner	Average patient to tube/film head axial rotation was 0.56° on nasium films. It was calculated that this amount of axial rotation would affect atlas laterality by 0.2°.
Seeman et al, 1994	1 film, 43 examiners	Atlas laterality was determined by angular measurement on the nasium film. The mean difference was 0.55 degrees. 40% of the group was within 0.25 degrees of the and almost 75% were within 1 degree. Only 1/43 doctors found found laterality on the opposite side.
Sigler, Howe, 1985	20 nasium films, 2 examiners, Atlas laterality	The absolute average of 20 measures was 1.55° for one examiner, with an average absolute difference between each pain of measures of 1.10°. For the intrarater assessment of examiner 2 the corresponding numbers were 2.01° and 0.82° deg. Intraclass correlation coefficients ranged from 0.70 to 0.86. Note: This study has been critically reviewed.[57,58]
Spencer 1989	Experienced examiners vs. students, nasium	Atlast laterality (UA) on the nasium was found to have an inter-examiner error of 0.33°. Experinced doctors versus students did not effect the error margin.
Troyanovich et al, 2000	30 films, 3 examiners	Intra-examiner T(x) distance: 0.99 -1.00, vertebral apex: 0.96- 0.97; Rz: 0.94-0.98; CDA: 0.92- 0.95. Inter-examiner for 3 examiners ranged (0.97- 0.99).

Table 3. Lateral Cervical Reliability Studies

Author, Year	Films, Examiners	Findings
Cote P et al, 1997	30 films, 3 examiners	Apophysial joint degen: Intra-CC = 0.45 degen disc disease: Intra-CC = 0.71; Cobb C2-C7 Intra-CC = 0.96, error =8.3º.
Frobin W et al, 2002	135 films	Height C3-C7 & disc height C2/C3-C6/C7 small errors of 3.9% and 5.7%. PA displacement C1/C2 to C6/C7 small error of 2.8% of mean vertebral depth & dens-atlas gap small error of <1.8% of the depth of C2.
Harrison DE et al 2000	30 films, 3 examiners	Posterior tangents are more reliable than Cobb angles, SEM ≤ 3°, 28out of 34 Intra- & Inter- ICCs were ≥ 0.7; the other 6 were 0.6 < ICC < 0.7.
Hardacker JW et al, 1997	30 films, 2 examiner	Intra- & inter-observer ICCs for sagittal alignment measures had strong correlation.
Herrmann AM, Geisler FH, 2004	27 films, 4 examiners	High intra- & inter-class correlations & low measurement errors (1.8º & 0.7mm).
Jackson BL et al, 1993	65 films, 3 examiners	For all segmental & global angles intra- & inter-examiner ICCs > 0.70.
Marshall and Tuchin, 1996	500 films, 2 observers,	Lordosis C1-C7 was evaluated. The mean absolute differences in rating between examiner one and two was 0.9 degrees. Mean signed difference = 0.04 with a 95% CI (-0.07, 0.14). The SD of differences is 1.17 so that 95% of differences in ratings between individual patients in the population from which this sample is drawn are predicted to lie in the range -2.31 to 2.38.
Peterson et al, 1999	48 films	Interexaminer and intraexaminer reliability of determining pillar hyperplasia was fair to substantial (kappa = 0.4 to 0.61; 75% to 92%).
Shoda N et al, 2005	30 films, 5 examiners	Intra-observer mean errors: Chamberlain line, McRae line, & McGregor line were 2.0º, 4.7º, & 1.5º respectively; intra-observer ICCs: 0.956, 0.835, and 0.975. Inter-observer mean errors: Chamberlain line, McRae line, & McGregor line were 2.3º, 5.0º , & 1.4º respectively; inter-observer ICC: were 0.939, 0.802, & 0.972.
Siersbaek-Nielsen & Solow, 1982	30 patients, 2 occasions 1-35 days, 3 examiners	Error: whole group was 2.3° for head position in relation to true vertical (NSL/VER), 3.1° for cervical inclination (OPT/HOR), and 3.4° for craniocervical angulation (NSL/OPT).
Silber JS et al, 2005	40 films, 3 examiners	Less intra- & interobserver variability for Gore method than for Cobb method (P < 0.05). 95% confidence limits for intra- & inter-observer variability for Gore method were 3°- 6º for group 1 & 4°- 7º for group 2. Cobb method, values were 4º- 9º for group 1 & 5º- 9º for group 2.
Stupor et al, 2003	50 radiographs, 2 examiners	Inter-examiner reliability of detecting cervical pillar hyperplasia was moderate with a kappa coefficient of 0.51.
Weigand et al, 2003	1 film digitized 10 times, 2 examiners	Of the 22 measurements obtained, 20 measurements demonstrated a SD of less than 20% of the average measured value. The inter-examiner SD's were within 1 degree and 1 mm for 20/22 measurements.
Takeshita K et al, 2001	295 films, 1 examiner	Mean cervical curvature index (Ishihara) = 10.9 ±15.3 & mean C2-7 angle =20.3º ±14.3º. A highly significant correlation (0.95) was found between cervical curvature index (Ishihara) & C2-7 angle. correlation diminished with S-shape.

Table 4. Flexion/Extension Cervical Reliability/Validity Studies

Author, Year	Films, Examiners	Findings
Cannada LK, 2003	27 films, 3 examiners	Cronbach's alpha: 0.95 for spinous process method & 0.74 for Cobb angle.
Capaccioli L et al, 1998	31 films, 4 examiners	Results show a high level of agreement of absolute measurement error between examiners.
Dvorak et al, 1988	28 healthy adult, 31 patients, 2 examiners	Penning's method: No statistically significant difference at any level was found when comparing the results of Examiner 1 with Examiner 2. Buetti-Bauml method: Produced significant interobserver difference in some of the measured values.
Frobin W et al, 2002	137 films	Segmental motions: Small errors (2º & 0.7mm), Quantifies segmental motions: Hyper, hypo, normal.
Harrison DE et al, 2000	30 films, 3 examiners	34 intra- & inter-class ICC, 28 were in the high range (>0.7), and 6 were in the good range (0.6-0.7). Cobb C1-C7 overestimated the cervical curvature (-54 degrees); at C2-C7 it underestimated cervical curve (-17 degrees), from posterior tangents (-26 degrees from C2 to C7). Inferior vertebral endplates and posterior body margins did not meet at 90 degrees: C2: 105°, C3: 99.7°, C4: 99.9°, C5: 96.1°, C6: 97.0°, C7: 95.4°, so segmental Cobb angles to underestimate lordosis at C2-C3, C4-C5, C6-C7.
Lind B et al, 1989	70 films, 1 examiner	Intra-observer error = ±1.8º. Range of axial rotation was measured (compass) on the subject's head. Intra-observer error with this technique was ±6 °. Largest flexion-extension motion occurred at C4/C5 and C5/C6. A linear decrease of motion in all directions, except flexion, was found with age.
Phillips FM et al, 1999	30 sets, 1 examiner	Radiographic measures of occipitocervical neutral position are reliable, repeatable, and simple to determine on routine lateral radiographs.
Schops P et al, 1999	40 films, 5 examiners	Selectivity of $p < or = 0.05$ and $p < or = 0.01$ is sufficient to distinguish patients from healthy subjects. The correlation between reviewers showed good to very good results ($0.6 < r < or = 0.8$; $r > 0.8$).
Wellborn CC et al, 2000	144 films, 3 examiners	ADI has greatest intraobserver agreement compared to Wiesel-Rothman measurement, occiput atlas angle, and Power's ratio. Fair interobserver agreement for ADI and Wiesel-Rothman, & better than Power's ratio.

Table 5A. AP/PA Thoracic and AP Full Spine Reliability Studies

Author, Year	Films, Examiners	Findings
Adam CJ et al, 2005	12 CT scans, 5 examiners, 3 occasions	For major curves, 95% confidence intervals for intra- & inter-observer ±-6.6º & ±7.7º, respectively. For minor curves, the intervals ±7.5º & ±8.2º, respectively. Intra- & inter-observer error of measurement 2.4° & 2.7°, with reliability coefficients of 88%& 84%, respectively.
Adam CJ, Askin GN, 2006	19 CTs, 3 examiners, marked 3 times	Confidence intervals (95%) for intraobserver & interobserver variability using manual methods were 5.5º-7.2° . mean difference between automatic and manual rotation measurements was -0.5º ± 3.3° for Aaro's method & 0.7°± 3.4° for Ho's method. mean difference between automatic & manual rotation measurements for the 204 endplate images was 0.25 º±3.8°.
Beekman, Hall, 1979	2 examiners, 10 films Full spine films, measured one time, Cobb method where examiners choose curve levels each time	Mean absolute values of observer differences: 4.2° ± .95°. 95% confidence interval was calculated as: 2.1°-6.3°. Pearson r = .66, p < 0.025. Note: that this study allowed examiners to choose the curve end points. With defined endpoints, errors are much smaller.
Berliner Let al, 2002	5 films, 1 examiner	Cobb data indicates an accuracy within 1 to 2 degrees for two computer methods: AccurView & Osiris
Burk et al, 1990	20 films, 2 examiners	Cohen's kappa was used for assessing inter-rater agreement. Intra-rater reliability of examiner 1 was "fair" at each of the 6 pre-selected spinal levels. Examiner 2 obtained reliability of "moderate" at 4/6 of the preselected levels and "fair" for the other 2/4. Inter-rater reliability at 4/6 of the sites was "slight" and "fair" at the remaining 2/6.
Capasso G et al, 1992	Review article	Paper identified, define, and discussed all possible errors in Cobb analysis of scoliosis.
Carmen et al, 1990	8 scoliosis, 20 kyphosis, 5 observers, 2 occasions	Overall standard deviation (the square root of the variance-component total) was 2.97 degrees. The square root of the intraobserver variance component is 2.78 degrees. The value of K for the sample of eight is 2.43813. Ion absence of any true change one can be 95% confident that 95% of the time the second value for the Cobb angle will be no more than 9.6 degrees more or less than the first due to observer error alone.
Cheung J et al, 2002	AP & lateral: 30 AP, 10 lateral, 5 observers	Mean intraobserver CR = 3.1 ° for AP Cobb angle & 3.3º for kyphosis Cobb angle. mean difference in the intra-observer CR of the Cobb angle between measurements made by placing landmarks and those made by drawing lines was not statistically significant (P>0.05). The mean intra-observer CR for the other parameters: for lateral deviation it was 0.8 mm, for axial rotation 4.0 ° and for length of the spine 3.3 mm.
Chockalingam N et al, 2002	9 films, 10 observers, 3 occasions	Computerized method : Intra-observer technical error of measurement (TEM) = 0.739º (98% error free), inter-observer TEM = 1.22º, mean coefficient of reliability = 0.988 Manual method: inter-observer TEM = 1.855º, coefficient of reliab. = 0.781.
Dang NR et al, 2005	10 films, 2 examiners, 5 times	PA & lateral: Intra-examiner reproducibility was generally excellent for parameters measured from PA radiographs but only fair to good for parameters from the lateral radiographs, in which some landmarks were not clearly visible. 7/13 parameters had excellent inter-observer reliability.
Desmet et al, 1982	78 patients (128 curves), 2 films taken same day-AP vs. PA, 2 observers	Angles were highly correlated (r=0.96). The PA radiographs revealed a larger curve for the thoracic curves (2.4 degrees, P<0.0001) and lumbar curves (1.7 degrees, P<0.031) nd the same for thoracolumbar curves.
Goldberg et al, 1988	30 films, 4 observers	Excellent intraclass correlation coefficients (Rho= 0.98). The standard deviation of intra-observer variation for the measured "primary" Cobb angle was 2.5 degrees and the intra-reader error, based upon the re-assessment of 15 films was 1.9 degrees. The "secondary" Cobb angle had an interrater agreement lower (Rho= 0.52), because smaller curves were less often noticed.
Gross et al, 1983	20 films, 28 scoliotic curves, 3 observers, 10 times each (5 manual+5 digitized)	2 way ANOVA showed no significant differences among the 3 observers or between the 2 methods. The correlations for the three observers were 0.94, 0.93 and 0.87. All these correlations were significant at p<0.01.
Jeffries et al, 1980	157 films, 5 examiners	Cobb method was compard with a computerized method. There was a 0.968 positive correlation between methods. Standard deviations for the manual Cobb method were between 2.1 and 3.6 degrees.
Kittleson and Lim, 1970	Opinion paper/review	Ferguson method should be used for curves under 50 degrees and the Cobb method for those curves over 50 degrees.

Table 5B. AP/PA Thoracic and AP Full Spine Reliability Studies

Author, Year	Films, Examiners	Findings
Kuklo TR et al, 2005	30 sets of pre-post,	PA, lateral & side bending: common radiographic parameters for AIS assessment demonstrated good or excellent reliability for digital measurement and can be recommended for routine clinical & academic use.
Kuklo TR et al, 2005	30 sets, 3 examiners	PA & lateral & side bending: majority of the radiographic parameters assessed demonstrated good or excellent intra- and inter-observer reliability.
Kuklo et al, 2006	30 AP full spine and bending films, 2 examiners, 9 variables, 2 times by hand, 2 times digitally.	Digital measurments showed decreased variability for 6/9 variables, however magnitudes were small. Combined intraobserver error for both methods: Cobb angle = 2°-3°, Side bending Cobb = 3°-4.3°, Plumbline to apex = 3.4mm-4.4mm, Coronal balance = 2.8mm-3.8mm, T1 Tilt = 2.3°-3.13°, LiV Tilt = 2.6°-3.0°, L1 inferior disc angle = 2.15°-2.8°, Apical rotation = 0.23°-0.43°, Riser grade = 0.31°-0.79°.
Lantz et al, 2001	40 curves, 1 examiner, 2 times	Demonstrated a minimal 0.6° margin of error for intra-examiner test-retest reliability.
McAlindon RJ et al, 1997	50 films, 3 examiners, 3 occasions	AP & rib-vertebral angle: Intra-observer error = 4.4º. Inter-observer error = 3.6°. Inter-observer accuracy = 6.2 º.
Morrissy et al, 1990	50 films, 4 observers	The pooled results of all four observers suggested that the 95 per cent confidence limit for intraobserver variability was 4.9 degrees for Set I, 3.8 degrees for Set II, and 2.8 degrees for Set III. The interobserver variability was 7.2 degrees for Set I and 6.3 degrees for Sets II and III.
Neugebauer et al, 1972	2 spines, several exposures with axial rotation of specimen and tube tilt	Absolute differences between the control and the examined exposures had a mean value of 1.15 +/- 0.98 for the Ferguson method and 2.06 +/- 1.09 for the Cobb angle in the first specimen and 0.60 +/- 0.21 and 0.98 +/- 0.31 degrees , respectively for the second. Axial rotation of the spine or elevation of the tube alone or in combination produced "differences in the measurements of the spinal deformity, which, however, hardly surpass the margins of error of the measurements."
Oda e al, 1982	50 AP full spine films, 5 observers, 2 occasions.	Average error was +/- 9 degrees (Cobb angle). The design of the study forced examiners to choose the end vertebrae blindly from test to re-test. This is where most error occurs. This would not be the case when a doctor is marking pre and post films in a clinical setting.
Omeroglu et al, 1996	3 patients, 54 observers (grouped according to experience)	No statistically significant difference ($P > 0.05$) between the averages of the final measurements of the three groups of examiners. The one film with the largest Cobb angle and largest apical rotation, significant difference ($P = 0.03$) between groups. Intra-observer variation, no statistically significant differences for apical rotation ($P > 0.05$).
Pruijs et al, 1994	Phase 1: 10 fusion scoliosis patients, 3 serial radiographs Phase 2: 46 x-rays, 3 observers	Phase 1: The standard error in the production of the radiograph on the same patient with a series of 3 films (the second and third films being taken at least one year following the first) was 2.2 degrees. The standard error of interobserver measurement variation ws 1.4 degrees. Extent of error was not associated with magnitude of Cobb angle.
Russell GG et al, 1990	8 vertebral positions, 3 examiners	No significant difference in calculated rotation of two vertebrae, or between three markers. Stokes's method was significantly the least accurate. The other three methods were not significantly different but Bunnell's method appeared to give more consistent results.
Sevastikoglou et al, 1969	1 scoliotic skeleton, then taken apart and reassembled	The absolute differences inmeasurements between the control and the examined exposures had a mean value of 1.15 +/ 0.98 degrees for the Ferguson measurement and 2.06 +/ 1.09 for the Cobb method in the first specimen and 0.66 +/- 0.21 and 0.98 +/- 0.31 for the second.
Shea KG et al, 1998	AP scoliosis 24 films, 6 examiners	Manual measurements: intraobserver variability was 3.3 degrees. For the computer set, the value was 2.6 degrees.
Taylor JA, 1993	Review, reliability & clinical relevance	AP full-spine radiography is an effective diagnostic and analytic procedure with an acceptable risk/benefit ratio. "Promising to excellent inter- and intraobserver reliability for some parameters."
Wilson et al, 1983	1 x-ray, 38 examiners	The average curve measured was 22.2 degrees (SEM=+/-0.84 degrees).
Ylikoski et al, 1990	30 scoliosis films	The 95% confidence interval for the interobserver error when measuring the scoliotic angle and % vertebral rotation was 5.7° and 6.9%. The intraobserver error was reported at a 95% CI = 3.7 deg and 3.7% for scoliosis angle and axial rotation, respectively. The interobserver measurement error (SD) was 2.8° for the Cobb angle and 1.8% for the vertebral rotation.
Zmurko MG et al, 2003	50 films, 4 examiners	No significant difference in the intra-observer or inter-observer variance between the digital and traditional groups. Digital radiographs are comparable to traditional radiographs.

Table 6. Lateral Thoracic Reliability Studies

Author, Year	Films, Examiners	Findings
Goh S et al, 2000	95 films, 3 methods	Strong correlations between angle and curvature for all 3 methods.
Harrison DE et al, 2001	30 films, 3 examiners	All three methods: global angle inter- & intra-examiner ICC > 0.94. Segmental angles, inter-observer and intra-observer ICCs in ranges (0.59-0.75 and 0.75-1.0). Mean absolute differences of observers' measurements are small (0.9º-2.5º).
Kado DM el al, 2006	120, 1 examiner	Mean of both the manual and digitized Cobb angle was 45 degrees (range 18°-83º),& mean Debrunner kyphometer reading was 48°(range 17°-83°). ICC between either of the 2 measures of the Cobb angle and Debrunner measurement was 0.68. ICC between the manual and digitized Cobb angle was 0.9.
Keynan O et al, 2006	Systematic review	Recommend radiographic parameters routinely for thoraco-lumbar fractures: Cobb angle, for sagittal alignment; vertebral body translation %, for traumatic anterolisthesis; anterior vertebral body compression %, for vertebral body compression, the sagittal-to-transverse canal diameter ratio, & canal total cross-sectional area; % canal occlusion, for canal dimensions.
Kuklo TR et al, 2001	50 films, 3 examiners	Intraclass correlation coefficients best method 1 (rho = 0.83-0.94); Method 4 (rho = 0.65-0.89); Method 5 (rho = 0.73-0. 85). Intra-observer agreement (% of repeated measures within 5 degrees of the original measurement) ranged between 72% and 98% for all techniques for all three observers; inter-observer reliability correlation coefficients ranging from 0.52 - 0.93. Method 1 highest inter-observer reliability coefficient (0.81, range 0.71-0.93) followed by Method 5 (0.71, range 0.68-0.75).
Rosol et al, 1996	23 films, 5 examiners—digitized films—morphometry	The coefficient of variation for interobserver variation was 2%. The mean deviation of an individual examiner from the group average was 0.63+/-0.62 mm. Intraobserver variability was also minimal, with differences in measured values falling between 3 to 5% and randomly distributing around zero. Regarding validity, a phantom was used with known dimensions. Measurements were distributed around the National Institute of Standards and Technology standards, indicating no systematic error. Longitudinal reproducibility was studied using 20 cases of 3 serial thoracic and radiographic studies, each one year apart. Coefficient of variability for the three aspects on the vertebral body height (anterior, middle and posterior) were low (4-6%).
Singer KP et al, 1990	286 films, 1 examiner	Computer method was more reliable, producing a coefficient of variation of 1.4% on repeated measurement.
Singer KP et al, 1994	22 films, 1 examiner	In vivo and in vitro measurements strongly correlated (Cobb angle r = 0.95, curvature r = 0.78). Trends decreased slightly in Cobb angle (1.3%, -2.6%) and increased slightly in curvature (10.7 mm, 4.1%).
Stotts AK et al, 2002	30 films, 4 examiners	Intraobserver variance = 4.3º. One examiner had significantly better precision (P= 0.02). This examiner's mean intra-observer difference= 2.3°.

Table 7. AP Lumbar & Ferguson Reliability Studies

Author, Year	Films, Examiners	Findings
Haas et al, 1990	43-58 AP lumbar and bending fims, 3 examiners, 1 time	Inter-segmental lateral bending and rotation angles. Majority of mean absolute differences between observers was 2° or less. Level of agreement for rotation around gravity was greater. L1-L4 reliability was determined to be good while L5 was poor. However, the 3rd examiner received copies instead of actual radiographs.
Harrison DE et al, 2002	30 films, 3 examiners	5 Intra- & Inter-examiner ICCs > 0.88. 3 ICC values (0.61, 0.76, 0.78) concerned determining the sacral base. Mean absolute differences of observers' measurements were 1.1 degrees to 1.8 degrees for angles and 1.2 mm to 2.3 mm for distances.
Quint DJ et al, 1997	AP & lateral lumbo-sacral: films, examiners??	Intra- and inter-observer measurement of spondylo-listhesis, disk space height, disk space angle, and vertebral body height are extremely reproducible.
Thorkeldsen A, Breen AC, 1994	8 films, 10 measurements, 1 examiner	For radiographs of diagnostic quality the gray scale range and midpoint level over the area of interest does not affect the reliability of coordinate marking.
Tilley 1966	100 films, 3 methods, 10 times, 1 examiner	Intrinsic variation was found to be approximately 1 mm with a SD of 0.5 mm. Comparison of sacral base values was r = 0.979, 0.97 and 0.99 ($p < 0.01$)
Troyanovich et al, 1999	30 films, 3 examiners	Intra-examiner: horizontal base angle ICC (0.72 -0.94), lumbodorsal angle ICC (0.90-0.96); lumbosacral angle ICC (0.84-0.96), & thoracic Tz ICC (0.95-0.97). Inter-examiner ICCs ranged 0.71 to 0.97.

Table 8. Lateral Lumbar Reliability

Author, Year	Films, Examiners	Findings
Chen 1999	16 subjects, 3 films each, 3 observers, 2 occasions, Cobb L1-L5, L1-S1, Centroid method.	"Correlation coefficients of lumbar lordosis between the two methods ranged from 0.589 to 0.772 with participants standing upright (all $P < 0.05$). Interobserver reliability coefficients were 0.903 for vertebral centroid measurement of lumbar lordosis, 0.826 for Cobb (L1-L5), and 0.784 for Cobb (L1-S1). Intraobserver r greater than 0.9. The vertebral centroid measurement of lumbar lordosis showed the smallest mean absolute differences between any two observers' measurements (< 1.7°)."
Chernukha et al, 1998,	199 supine lumbar radiographs, 3 observers, Cobb L1-S1, TRALL.	Spearman-Brown coefficients for parallel measurements obtained by analysis of variance for repeated measurements were .99 for each rater regardless of which method was used. Intramethod and interrater variability for TRALL was not significantly different than that for Cobb.
Frobin W et al, 1997	892 films, 2 examiners	Relative measurement error in vertebral height = 2.2%; for a vertebra of 30 mm height this corresponds to an error of approximately 0.7 mm. error in sagittal plane displacement amounts to 0.015 (measured in units of mean vertebral depth); for a vertebra of 35 mm depth this corresponds to an error of 0.5 mm. error in disc height amounts to 4.15%; for a disc of 10 mm height this corresponds to approximately 0.5 mm.
Gilliam et al, 1994	15 films, 2 radiologists	The ICC's for intratester reliability for radiological measurements were 0.92 and 0.95 for the sacral angle and 0.98 for the 2 measurements of pelvic angle. Intertester reliability were 0.86 and 0.88.
Harrison DE et al, 2001	30 films, 3 examiners	Inter-& intra-observer ICCs > 0.83 for all segmental and global angles. mean absolute differences of observers' measurements were small (0.6º -2.0º).
Pfeifer et al, 2003	45 films,	Measurement of intervertebral space height and sagittal translation: DCRA appears to be more reliable than CALSM.
Phillips et al 1986	99 films, 4 examiners 'recording' each or 56 variables. Examiners were not experienced at all variables.	Although 56 variables were recorded, many contained no numerical measurement. Cronbach's Alpha used to express reliability, no ICC's and no standard errors of measurement were reported. 16/56 variables had agreement in the fair to moderat range (.6-.799) and 6/56 (short leg, sacral base, Ferguson's gravity line, spondylolisthese, spondylolysis, lumbarization) were in the excellent range (.8-1.0).
Polly etal, 1 998	60 films, 3 examiners, 4 different techniques, 2 occasions	Measured magnitude of lordosis 4 ways: L1-L5, L1-S1, T12-L5 and T12-S1. All intraclass correlation coefficients were within the range from 0.83 – 0.96. Interobservoer variability ranged from 0.81-0.92. Interrater reliability was consistently highest for the measurement of L1-L5.
Saraste H et al, 1985	12+170 films, 2 examiners	Radiographic evaluation of vertebral slipping and lumbosacral lordosis is equally reliable in the recumbent and standing positions.
Schuler TC et al, 2004	10 films, 12 examiners	Segmental lordosis at L4-5 & L5-S: Cobb & posterior body technique are least variable measurement.
Seel et al, 2005	24 films, 4 observers, 2 occasions, vertebral endplate cobb angles for fracture kyphosis measurement.	Intraclass coefficients were most consistent for method 2 (ρ = 0.856-0.976). Method 3 produced the lowest intraclass coefficients overall in our series (ρ = 0.846-0.919). A high level of intraobserver agreement was maintained when all results were pooled with respect to each observer. Each observer achieved 99% reproducibility. Method 2 (ICC = 0.95, CI = 0.926-0.967) had the best overall interobserver reliability. All three methods were well above the threshold of >0.8.
Shaffer WO et al, 1990	132 films-2 raters, 750 films-1 rater, 58 films-2 raters	High consistency & accuracy indices do not ensure acceptable false-positive & false-negative rates. Using roentgenograms as a basis for diagnosing instability often can lead to errors in classification. This is less so when observed translations are > (± 5+ mm) on roentgenograms that are relatively clear, with little obliquity, & concomitant motions are minimal.
Tibrewal et al, 1985	11 no pain 12 months, 10 with IVD disorder,	Intraobserver error (5 IVD's, one radiograph, five times, 2 times) showed a maximum difference of 0.7 mm from the mean of five readings in 50 sets of measurements. Interobserver error (2 observers all films) showed a maximum mean difference between observers of 0.75 mm at the L5-S1 level.
Troyanovic h et al, 1998	30 films, 3 examiners	Intra-examiner ICC: only T12-L1 intersegmental measure < 0.70. Inter-examiner ICC: for manual and computer-aided digitizing examiners: L1-5ARA 0.96; 0.84 for arcuate angle; 0.82 for Ferguson's angle; 0.88 for Cobb angle; 1.00 for Tz translation; & 0.65, 0.73, 0.74, 0.75, 0.89 and 0.81 for segmental angles T12-L1, L5-S1.
Troyanovic h et al, 1995	30 films, 3 examiners	Except arcuate angle, all segmental & global angle intra- & inter-examiner ICCs > 0.78.
Wilke et al, 2006	16 discs. X-rayed and measured grossly. Measurements were done by 2 observers.	The validation of the new radiographic grading system revealed a substantial agreement between the radiographic and the macroscopic overall degree of degeneration (Kappa=0.714, 95% CL: 0.587–0.841). The interobserver agreement was substantial for all the three variables and for the overall degree of degeneration (Kappa=0.787, 95% CL: 0.702–0.872).

Table 9. Lumbar Flexion/extension Reliability

Author, Year	Films, Examiners	Findings
Cakir B, et al 2006	24 films, 3 examiners, 2 methods	Inter examiner reliability: +/- 4° 95% confidence interval. Mean differences of observer measurements for intra examiner and inter = 1° or less
Fritz et al, 2005	49 flex. films 49 ext. films	Intraclass correleation coefficients for the various variables measured ranged from 0.84 to 0.99 for translation values, and 0.81 to 0.96 for angular measures.
Frobin W et al, 1997	892 lateral views of healthy male and female subjects	Small errors in measured disc height (0.7mm), vertebral height (0.5mm) and sagittal plane displacement (0.5mm)
Frobin W et al, 1996	61 films,	Error: angles less than 1.6º & translations 1.2 - 2.4% vertebral depth.
Harvey SB, Hukins DW, 1998	Biomechanics study	Lateral & flexion & Extension: The calculated centric provides a robust reference point for kinematic calculations.
Panjabi M et al, 1992	3 film pairs, 35 digitizations, 1 digitizer.	Error ranges (2 x SD) for the motion parameters were 1) rotation =±1.25 º; 2) translation of the inferior posterior vertebral body corner = ± 0.86°; and 3) coordinates for the center of rotation = +/- 4.3 mm. spinal level & radiographic quality affected magnitude of errors in all motion parameters.
Penning et al, 2005	5 sets of films, 3 examiners, 5 occasions	SEM for linear measurements = 0.1 to 0.8, and 0.3 to 2.3 for angular measurements.
Putto, Tallroth et al, 1990	20 patients, 2 flexion films, 2 extension each	Extension/flexion films taken by two different methods. Fairly acceptable correlations between inter-observer and intraobserver variations (r = 0.52-0.96 and 0.66 to 0.99, respectively) was reported.
Tallroth K et al, 1994	30 films, 3 examiners	Highest intra-observer angular variations at L5-S1 level (1.6°, ±1.6º, max. 9 °), highest sagittal translation at L5-S1 level (0.6 mm, ±0.8 mm, max. 4 mm). Highest angular inter-observer variation at L5-S1 level (2.6º, ±2.3°, max. 11º), highest variation in sagittal translatoion at L4-L5 level (1.4 mm±1.2 mm, max. 6 mm). Mean intra-observer variation for L5 spondylolisthesis was 1.0 mm±0.9 mm, max. 5 mm) & inter-observer variation 1.3 mm ±1.1 mm, max. 6 mm).
Teyhen DS et al, 2005	20 films, 1 examiner, intra and inter examiner reliability on fluoroscopic videos.	Lateral & flexion digital fluoroscopic video: Intra-image ICC =0.99, & SEM = 0.4-0.7ºand 0.2-0.3 mm. Inter-image ICC = 0.88, & SEM = 0.7-1.4° & 0.4-0.7 mm.

Table 10. Lateral Full Spine Reliability

Author, Year	Films/Examin	Findings
Berthonnaud E et al, 2005	30 films, 4 examiners	ICC measured within observers was between 0.93 -0.99, ICC between observers were 0.92 -0.99.
Faro FD et al, 2004	50 films	Biomechanics: The fists on clavicles position for lateral radiograph acquisition has less negative shift in SVA, less compensatory posterior rotation of the pelvis. This position is more representative of a patient's functional balance.
Jackson et al, 1998	50 volunteers, 50 lumbar degeneration, 30 low grade L5-S1 isthmic spondy, 30 idiopathic or degenerative scoliosis	Interobserver reliability for sagittal spinopelvic parameters ranged from 0.77-0.99, (P <0.05). Intraobserver reliability for the majority of sagittal spinopelvic parameters measurements was in the good to excellent range in each group.
Jackson et al, 2000	20 subjects 2 films each	The most reliable measurements were PRS1 (for pelvic morphology), PA and HASP (for pelvic balance), and PRL3 and PRL4 (for regional lumbopelvic lordosis) by the pelvic radius technique, with $r \geq 0.96$ ($P < 0.0001$ for all correlations). The reliability correlation coefficients for pelvic balance measurements ranged from 0.99 to 0.95, and those for spinal balance ranged from 0.97 to 0.40.
Jackson RP et al, 2003	150 films, 2 examiners	Mean slippage for patients was 30% (range, 11-85%), with 34 patients (45%) having Grade I slips, 32 (43%) having Grade II slips, & 9 (12%) having Grade III & IV slips. mean measurements between patients & volunteers were significantly different (P < 0.01) for lumbar lordosis, pelvic lordosis, and lumbopelvic lordosis.
Kuklo et al, 2006	30 films, 2 examiners, 6 variables, 2 times by hand, 2 times digitally.	Only difference between 2 methods was for T2-T5 regional kyphosis: manual error 5.41 vs. 7.19 digital. Combined method errors for all variables were T5-T12 = 6-7, T2-T12 = 4-5, T10-L2= 4-5, T12-S1= 4.98-5.3, Sagittal balance C7-S1= 6-7mm. "Digital measurement showed decreased measurement variability (increased precision) for the majority of commonly used AIS parameters". Both had small errors.
Plaugher et al, 1990	3 examiners, 20 subjects for inter-examiner of retrolisthesis and cervical lordosis (Cobb C1-C7 and C2-C7), 1 examiner for intra.	Intra- and inter-examiner reliability for cervical lordosis & retrolisthesis were excellent & low standard error Pearson's r = 0.89-0.97, p < .001 for cervical lordosis & Pearson's r = 0.74-0.90, p < .001 for retrolisthesis.
Rajnics P et al, 2001	30 films, 2 examiners & 10 films, 1 examiner, 10 times	Interobserver repeatability: variables are more repeatable (< ±1.5°) when the operator is experienced. A less (±-6.5º) repeatable measurement is T4-T12 kyphosis, due to poor contrast on radiographs of the upper thoracic vertebrae. Both AP & lateral films on 30 subjects were used.
Rillardon L et al, 2003	100 films, 5 examiners	Manual measurements & computerized measurements: intra-class ICCs from 0.82 to 0.96. Inter- and intra-observer variabilities were comparable for the measurement techniques for thoracic kyphosis, lumbar lordosis, pelvic index, pelvic tilt, and slope of the sacrum. Inter- and intra-observer variability was lower when the sagittal tilt was measured with the computer.
Vedantam R et al, 2000	80 films,	Biomechanical study: authors recommend positioning the arms at 30 degrees of forward flexion from the vertical.
Vialle R et al, 2005	300 films. Biomechanical study	Mean values were 60º, 10°for maximum lumbar lordosis, 41º±8.4° for sacral slope, 13 º±6°for pelvic tilt, 55 °±10.6 º for pelvic incidence, and 10.3 °±3.1 º for T9 sagittal offset. Strong correlation ofsacral slope and the pelvic incidence (r = 0.8); for maximum lumbar lordosis & sacral slope (r = 0.86); for pelvic incidence & pelvic tilt (r = 0.66); between maximum lumbar lordosis & pelvic incidence, pelvic tilt, and maximum thoracic kyphosis (r = 0.9); between pelvic incidence & T9 sagittal offset, sacral slope, pelvic tilt, maximum lumbar lordosis, & thoracic kyphosis (r = 0.98).
Ylikoski et al, 1990	30 lateral films	In measuring vertebral body height, the interobserver error of measurement (SD) was 3.2 and the intraobserver, 2.6 degrees. For the intervertebral disc height the interobserver error was 2.4 and the intraobserver, 1.8 degrees. These angles were transformed into height to length ratios.

Table 11. AP & Lateral Pelvic Reliability

Author, Year	Films/Examin	Findings
Hamberg J et al, 1993	20films (mounted phantom), 4 examiners, measured 3 times	Lateral: two methods & x-ray measurements showed high reliability, hypothesis of a more posterior tilted pelvis in the new method was confirmed. Pearson's correlation coefficients: length measurements = 0.81–0.98 ($P < 0.0005$), with fine tuning of contrast = 0.96 – 0.99 ($P < 0.0005$). Angular measurements = 0.99-1.00 ($P<0.0005$), linear measurements = 0.99-1.00 ($P<0.0005$)—same with fine tuning the contrast.
Boniforti FG et al, 1997	60 films, 3 examiners	AP: errors acetabular index were E1 ±5º, E2 ± 5 º, and E3 ± 3.5º. Yamamuro's measurement of lateral femoral displacement was more reliable than the Hilgenreiner distance. Errors of indicators of pelvic alignment showed a correlation with the age of the infant; the quotient of pelvic rotation was more reliable after seven months of age ($p < 0.0001$). Errors of symphysis os-ischium angle tended to increase with age & index of pelvic tilt decreased with skeletal maturation ($p = 0.002$).
Plaugher et al, 1993	37 subjects, 2 films, 2 examiners, measures 1 hour or 18 days apart.	For radiographic of Gonstead pelvic line drawing: no statistically significant differences in any measurement.

Table 12. Lower Extremity Reliability (short leg analysis)

Author, Year	Films/Examin	Findings
Clarke 1972	50 films	Skeleton positioned for initial establishment of face validity showed an accuracy of 3 mm at 100 cm tube film distance. Palpation of iliac crests was only accurate in 16/50 subjects within 5 mm, while 20/50 were accurate within 5 mm when using the tape measure method.
Fann et al, 1999	52 films, 4 raters, 2 occasions	Measured unlevelness with line of eburnation and the intersulcate line. Interrater correlation coefficients for the line of eburnation ranged from 0.82 to 0.9 and from 0.90 to 0.92 for the intersulcate method. Intrarater correlation coefficient was 0.81 to 0.84 for the line of eburnation and from 0.93 to 0.95.
Friberg et al, 1983	789 pain patients, 359 symptom free	Repeatability: 25 subjects repeat test/measurement and 5 to three times at 1-30 month intervals. Also 30 persons re-examined with a lift exactly the same size of the pre-measured lift. The mean error in all these repeated measurements was 0.6 mm, and it never exceeded 2 mm. Only 8% of all subjects had equal leg lengths
Friberg 1985	20 films, 2 occasions	Mean error of measurement was 0.6 mm (range 0-2.0 mm). The second film was taken with a lift under the foot. Radiation doses were low.
Giles, 1981	AP Pelvic	Leg length inequality: 1.12mm ± 0.92.
Gofton and Trueman, 1971	AP Pelvic67 films	Leg length inequality: 1.44mm ± 1.06.
Greenman et al, 1979	200 patients	This series falls within the margin of error of up to 1.5 mm of measurement.
Hamer OW et al, 2004	20 films, 4 examiners	Difference between the observers' angle measurements and the standard of reference was 0.4° distance measurements, mean discrepancies to the standard were 0.2 cm (femur) and 0.1 cm (tibia) for manual fine tuning & 0.5 cm & 0.7 cm, without manual correction
Kujala et al, 1987	121 w/knee injury, 20 w/out	Correlation coefficients for all rereadings were excellent (0.99-1.00), being 0.99 for the LLI (mm).
Leppilahti J et al, 1998	101 surgical films, 87 controls	The mean difference of measurements ranged from 0 to 2 mm (mean = 1 mm, SD = 0.8 mm: correlation of coefficient = 0.96)
Rozzanigo U et al, 2005	40 films, 2 examiners, 20 films, 5 examiners	Computer-aided evaluation of alignment & articular orientation parameters of lower limbs is as accurate & reliable as the traditional manual method, but is faster and allows better-quality images.
Rush et al, 1946	1000 subjects	Only 23% (N=230/1000) had equal femur head heights
Siu D et al, 1991	30 knee films, 4 examiners, 8 repositions	AP & lateral: greatest error was random. Most angles were reproducible within ±1.3 ° or less at 95% confidence.
Stricker SJ, Faustgen JP, 1994	33 films, 1 examiners	Intraobserver SEMs < 2.1 & all ICCs > 0.93.
Terry MA et al, 2005	16 films,4 examiners	Intraobserver (4 examiners & 4 films) variance of direct slit scanogram measurement included intraclass ICC = 0.99, mean difference of 0.1 cm
Wright JG et al, 1993	Biomechanical study	If limb was rotated no more than 10 ° from neutral, effect on apparent axial alignment was minimal & measurement was reliable.

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