Topics in Diagnostic Imaging

Exploratory Evaluation of the Effect of Axial Rotation, Focal Film Distance and Measurement Methods on the Magnitude of Projected Lumbar Retrolisthesis on Plain Film Radiographs

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Abstract

Objective: The purpose of this exploratory study was to evaluate the amount of error in retrolisthesis measurement due to measurement methods or projection factors inherent in spinal radiography. In addition, this study compared how accurately these methods determine positions of the lumbar vertebrae being studied and the expected projected size of the retrolisthesis.

Methods: Vertebral models were situated in a retrolisthesis position. Radiographs of the models were obtained in positive and negative y-axis rotations at 40- and 84-in focal film distances. The projected retrolisthesis was measured using the Gohl, Iguchi, and Lopes methods.

Results: At the 40-in focal film distance, the Iguchi method and Lopes methods were significantly more accurate than the Gohl method. At the 84-in focal film distance, the Lopes method was significantly more accurate than the Gohl method. Almost all measurements overestimated both the actual amount of retrolisthesis as well as the amount of trigonometrically calculated retrolisthesis that should have been present on the radiographs. Findings suggest that measurements were less accurate with vertebrae rotated more than 10°.

Conclusions: This study demonstrated that lumbar vertebral rotation, focal film distance, and measurement methods are potential sources of error in retrolisthesis measurement.

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Introduction

Diagnoses and clinical decision making for a variety of orthopedic conditions depend heavily upon radiographic studies; therefore, measurements derived from radiographs must be accurate.¹ This is especially true in the chiropractic profession with the existing controversy over the historical usage of radiographic measurement of the spine.² Gonstead manipulative technique was estimated to be used by approximately 58% of the chiropractic profession in 1998,³ although it is unknown how many use the Gonstead Method, which includes measurement of misalignment in its analysis system. Although the value of assessing relatively small spinal misalignments has been seriously questioned,⁴ some providers who use the Gonstead Method attempt to measure the amount of retrolisthesis seen on radiographs.^{5–7} Given that some practitioners use this technique, it would be important to know if the measurements derived from the radiographs accurately reflected the position of the vertebrae being studied.

Because of distortion related to pelvic rotation, the use of radiography in measurement of the pelvis has been questioned.^{8,9} As well, other issues have been raised, including a number of general measurement problems related to lumbar vertebrae such that x-axis translation of a vertebra results in projected y-axis rotation and that the irregular shape of the vertebrae can have unexpected effects on the projected image when they are rotated on the y-axis.^{10–13} These types of projection errors can lead to inaccurate analysis. Wall and Oppenheim¹⁴ have also noted that the determination of the progression of spondylolisthesis, a condition that commonly occurs in conjunction with retrolisthesis,^{15,16} may be hindered by projection errors. Given these findings, radiography is not an accurate tool for the assessment of spinal position; and different measurement methods have not been adequately tested. Clinicians could be using faulty information in their decision-making process. It is therefore important to determine if retrolisthesis measurement on radiographs is subject to significant error.

The purpose of this exploratory study was to evaluate if measurement of retrolisthesis, using the Gohl,⁶ Iguchi,¹⁷ and Lopes measurement methods, may have errors in the measurement methods themselves or the projection factors inherent in spinal radiography. Additionally, this study compared how accurately these measurements reflect the actual positions of the vertebrae being studied and the projected retrolisthesis expected to be found on the radiographs.

Methods

Plastic models of a fourth and fifth lumbar vertebra were used to demonstrate the effects of y-axis rotation and changes in focal film distance on projected retrolisthesis (Fig 1). Holes were drilled in the inferior body of the fourth lumbar vertebral model and the superior body of the fifth lumbar vertebra. A copper wire was inserted into these holes such that the relative positions of the vertebrae could be changed and maintained by the bending of this wire. An angle of 17° was then formed between the inferior end plate of the fourth lumbar vertebra and the superior end plate of the fifth lumbar vertebra by bending the copper wire.

To obtain the desired amount of posterior slippage, we selected a point at the mid line of the posterior inferior vertebral body margin of the fourth lumbar vertebral model and then measured from that point along the inferior of the vertebral body and placed a small line 5 mm from the posterior edge. The fourth lumbar vertebral body was then moved posterior until that mark matched with a point on the mid line of the superior posterior vertebral body margin of the fifth lumbar vertebral model. This produced a 5-mm retrolisthesis of the fourth on the fifth lumbar vertebral body.

The vertebrae were placed on a plastic pedestal. The center of the posterior inferior border of the fifth lumbar vertebral body was positioned on the center point of the pedestal, which was centered on the axis of a turntable upon which a Pickett Model 6180 protractor (Pickett Industries, Tucson, AZ) had been mounted to allow the assessment of the number of degrees the turntable was rotated. The turntable allowed the models to be rotated in both the positive and negative direction on the y-axis. The central axis of the turntable was then positioned on the center line of the bucky at a distance of 17 cm from the

Fig 1. Photograph of the models used in the study.

bucky (19-cm object film distance). The tube and the center of the bucky were positioned to be at the level of the disk space between the modeled vertebrae. The models were positioned parallel to the bucky with the right side of the models closest to the x-ray film. A Universal 300-mA/125-kilovolt (peak) x-ray machine (Del Medical Imaging Corporation, Franklin Park, IL) and a Konica QX7 automatic processor (Konica Corporation, Tokyo, Japan) were used to obtain the radiographs. Test radiographs were made at the 40- and 84-in focal film distances until acceptable clarity was found. When the appropriate settings had been established, all radiographs at the particular focal film distance were exposed using those settings. Radiographs were taken in this neutral position and at 5°, 10°, 15°, and 20° of both positive (the front of the body of the models rotated away from the x-ray film) (Figs 2-6) and negative (the front of the body of the models rotated toward the x-ray film) axial (y-axis) rotation and at both 40- and 84-in focal film distances. This amounted to 18 radiographs in total.

The resulting radiographic images were measured for the amount of projected retrolisthesis by one of the authors, who has 35 years of clinical experience and previous experience measuring findings on radiographs in previous studies. In addition, he was blinded as to which radiograph was being measured. In those instances in which he felt unable to determine the amount of retrolisthesis with reasonable accuracy because of circumstances such as not being able to clearly find marking points, the measurement was not analyzed. Three different measurement methods for assessing retrolisthesis were used.

Fig 2. Radiograph of the models in the nonrotated position at the 40-in focal film distance. The end plates and margins of the vertebral bodies that were the points used for analysis of the retrolisthesis are clearly visible.

Fig 3. Radiograph of the models rotated 5° in the positive direction on the y-axis at the 40-in focal film distance. The end plates and margins of the vertebral bodies that were the points used for analysis of the retrolisthesis are clearly visible.

Method 1

This method has been proposed by Gohl.⁶ A line is drawn along the superior end plate of the lower, in this case fifth lumbar, vertebra. At the posterior superior corner of the fifth lumbar vertebral body, a line is erected perpendicular to the fifth lumbar superior end plate line and extended inferiorly. Next, a line beginning at the posterior inferior corner of the fourth lumbar vertebral body is extended inferiorly and parallel to the line erected perpendicular to the fifth

Fig 4. Radiograph of the models rotated 10° in the positive direction on the y-axis at the 40-in focal film distance. The end plates and margins of the vertebral bodies that were the points used for analysis are seen, but changes in the projected image are seen.

Fig 5. Radiograph of the models rotated 15° in the positive direction on the y-axis at the 40-in focal film distance. The end plates and margins of the vertebral bodies that were the points used for analysis are visible, but significant changes in the clarity and the projected image are seen.

lumbar end plate. The distance between these 2 parallel lines is considered the amount of retrolisthesis of the fourth lumbar vertebra on the fifth lumbar vertebra (Fig 7). The measurements were made on the radiographs that had been taken with the models in the neutral or nonrotated position and when the vertebrae were rotated in the negative and positive y-axis directions in 5° increments up to 20° in each direction.

Fig 6. Radiograph of models rotated 20° in the positive direction on the y-axis at the 40-in focal film distance. The end plates and margins of the vertebral bodies that were the points used for analysis are seen; but very significant changes in the clarity and the projected image are present, making analysis unreliable.

Fig 7. Gohl method. A line is drawn along the superior end plate of the fifth lumbar vertebra. Two lines are erected perpendicular to this line to pass through the adjacent posterior vertebral body corners. The distance between these 2 lines indicated by X is the amount of retrolisthesis.

Method 2

This method has been used by Iguchi.¹⁷ A line is drawn along the inferior end plate of the fourth lumbar vertebral body. At the posterior inferior corner of the fourth lumbar vertebral body, a line is erected perpendicular to the inferior end plate line and extended upward. A second line is erected perpendicular to the fourth lumbar end plate line and extended downward to pass through the posterior superior corner of the fifth lumbar vertebral body. The distance between the points of intersection of the lines passing through the fourth and fifth lumbar vertebral body corners with the fourth

Fig 8. Iguchi method. A line is drawn along the inferior end plate of the fourth lumbar vertebral body. Two lines are erected perpendicular to this line to pass through the adjacent posterior corners of the vertebral bodies. The distance between the points at which these 2 lines intersect the end plate line indicated by X is the amount of retrolisthesis.

lumbar end plate line is determined to be the amount of retrolisthesis of the fourth lumbar vertebra on the fifth lumbar vertebra (Fig 8). This was done using the same radiographs that were measured in Method 1.

Method 3

This method was developed by one of the authors, Lopes, who did not perform the radiographic measurements. A line is drawn through the middle of the disk space between the fourth and fifth lumbar vertebrae. Two lines are erected perpendicular to this line. One passes through the posterior inferior corner of the fourth lumbar vertebral body, and the other passes through the posterior superior corner of the fifth lumbar vertebral body. The line from the posterior inferior corner of the fourth lumbar vertebral body is extended inferiorly to run parallel to the line drawn through the posterior superior corner of the fifth lumbar vertebral body. The distance between these 2 parallel lines is measured and determined to be the amount of retrolisthesis of the fourth lumbar on the fifth lumbar vertebra (Fig 9). This was done using the same radiographs that were measured in methods 1 and 2.

The results of these measurements were used in the process of obtaining 3 sets of numbers. First, the size of the projected retrolisthesis on the radiograph, as determined by using the 3 measurement methods, was compared with the actual modeled retrolisthesis size of 5 mm for the radiographs taken at 40 and 84 in. Second, as the image on the radiograph is a projection, the projected magnitude of the retrolisthesis on the radiograph will differ from the actual retrolisthesis of the model. The amount of the retrolisthesis that should

Fig 9. Lopes method. A line is drawn through the middle of the disk space between the fourth and fifth lumbar vertebrae. Two lines are erected perpendicular to this line to pass through the adjacent posterior corners of the vertebral bodies. The distance between these 2 lines indicated by X is the amount of retrolisthesis.

be seen on the film, expected retrolisthesis, was compared with the measured size of the projected retrolisthesis on the radiograph, as determined by using the three measurement methods for the radiographs taken at 40 and 84 in. Finally, the mean and standard deviation for each method at each focal film distance were determined as well as a comparison of measurement error between methods 1, 2, and 3 relative to the expected retrolisthesis.

The Magnitude of the Projected Retrolisthesis

To determine the magnitude of the projected retrolisthesis that should have been found on the radiographs, trigonometric calculations were made. A triangular expression of the angles and lengths involved in the equations is shown in Fig 10. Angle B represents the angle of the divergent rays at the source of the x-ray beam that contact the posterior aspect of the L5 vertebral body and the posterior L4 vertebral body, given the 5-mm retrolisthesis, used in our model. Angle C is 90° in this figure, representing zero y-axis rotation of the model. We used trigonometric ratios ($\tan B = b/a$) to determine angle B when the known object film distance was 19 cm and the focal film distance (FFD) was either 40" or 84" (101.60 and 213.36 cm, respectively). Angle B was then used to calculate the expected projected amount of retrolisthesis (calculated mathematically) using FFDs of both 40" and 84" employing the same trigonometric ratio equations.

Fig 11 shows the procedures used to calculate the changes in the projected retrolisthesis on the film when the model is rotated 5° and 10° at the time of exposures. For this calculation, the Law of Cosines was used [$c^2 = a^2 + b^2 - 2(a)(b)\cos C$]. We first determined the value for c. We then used the known variables of sides a and b and angle C (at 101.6 cm and 213.36 cm source to object distance) to calculate the angle B (using this variation of the Law of Cosines [$b^2 = a^2 + c^2 - 2(a)(c)\cos B$] because angle B (angle of divergence of the rays of the x-ray beam that contact the ends of the retrolisthesis) differs slightly from the calculations made with no y-axis rotation in the model between L4 and L5 compared with when y-axis rotation is present.

Angle B was then used to calculate the mathematically projected amount of measured retrolisthesis that should have been found on the lateral film for y-axis rotations of plus and minus 5° and 10° y-axis rotation of the model, using an FFD of both 40" and 84" with the same trigonometric ratio equations used in Fig 10.

Fig 10. Angle “B” is the angle between sides “a” and “c” that represent divergent rays from the x-ray source to the posterior edges of the fourth and fifth lumbar vertebrae and extending to the modeled x-ray film. They are offset because of the retrolisthesis of L4 on L5 in the vertebral model. Angle “C” is 90°, as there is no $\pm y$ -axis rotation of the model. Angle “A” is the angle between ray “c” and the side “b”. Side “b” represents the 5-mm-long modeled retrolisthesis.

Results

The magnitude of error of the measured projected retrolisthesis using the 3 measurement methods compared with the actual modeled size of 5 mm for the radiographs taken at 40 and 84 inches along with the mean and standard deviations are seen in Table 1. The person performing the measurements was able to accurately locate the points needed for analysis on only half of the radiographs in which the models had been rotated 15° and on none of the radiographs in which the models had been rotated 20°. The measurements made at 15° rotation have been included to show the discrepancies when compared with the other rotations; but the 20° rotations, none of which were analyzed, are not listed in the table.

According to our calculations, the amount of retrolisthesis that should have been seen on the radiograph at the 40-in focal film distance in the nonrotated position at $\pm 5^\circ$ and -10° of rotation was 6.1 mm. The amount that should have been found at $+10^\circ$ of rotation was 6.0 mm. The magnitude of the retrolisthesis that should have been seen on the radiograph at the 84-in focal film distance in the

nonrotated and at $\pm 5^\circ$ of rotation was 5.5 mm. The amount that should have been found at $\pm 10^\circ$ of rotation was 5.4 mm. The magnitude of error of the measured projected retrolisthesis using the 3 measurement methods compared with the projected amounts that should have been found, along with the mean and standard deviations, are seen in Table 2 excluding rotations of 15° and 20° because of the limitations noted above.

Regardless of the measurement method used or which focal film distance or axial rotation was selected, almost all measurements overestimated both the actual amount of retrolisthesis that was present in the models as well as the amount of trigonometrically calculated retrolisthesis that should have been present on the radiographs. This was true in all cases except for method 2 in the nonrotated position at the 40-in focal film distance, where the measured amount was less than the calculated projected amount that should have been found on the radiograph. However, the measurement error was significantly smaller in Table 2 because this table took into account the increase in retrolisthesis magnitude caused by projection.

Table 3 shows a comparison of the measurement error of methods 1, 2, and 3 relative to the expected

Fig 11. Θ_y represents the amount the model is rotated (angle C is no longer 90°) on the y-axis. The y-axis rotation changes the projected length of side “b,” which represents the 5-mm modeled retrolisthesis. Angle “B” decreases as the y-axis rotation of the model increases. As the model's y-axis rotation increases, the length of the projected retrolisthesis decreases.

Table 1 The Amount of Retrolisthesis Error in the Measurement of the Radiographs Compared With the Actual Retrolisthesis Size of 5 mm That Was Created by the Positioning of the Vertebral Models

Rotation	Method 1 (40 in)	Method 2 (40 in)	Method 3 (40 in)	Method 1 (84 in)	Method 2 (84 in)	Method 3 (84 in)
0 rotation	3 mm	1 mm	2 mm	2 mm	2 mm	2 mm
−5°	2.5 mm	1.5 mm	2 mm	2.5 mm	1.5 mm	1.5 mm
−10°	2.5 mm	2.5 mm	1.5 mm	3 mm	3 mm	1.5 mm
−15°	Not analyzed	Not analyzed	Not analyzed	8 mm	8.5 mm	6.5 mm
+5°	2.5 mm	1.5 mm	1.5 mm	1 mm	1 mm	1 mm
+10°	2.5 mm	1.5 mm	1.5 mm	1.5 mm	1 mm	1 mm
+15°	Not analyzed	2 mm	Not analyzed	Not analyzed	1.5 mm	6 mm
Mean	2.6	1.7	1.7	3	2.6	2.8
Standard Deviation	0.2	0.5	0.3	2.5	2.7	2.4

Those instances in which the author conducting the measurements felt that they were unable to determine the amount of retrolisthesis with reasonable accuracy are labeled *Not analyzed*. In all cases, the measured size was greater than the modeled size of 5 mm.

projected retrolisthesis. It reveals that, at the 40-in focal film distance, method 2 is significantly more accurate than method 1, method 2 is not significantly different than method 3, and method 3 is significantly more accurate than method 1. At the 84-in focal film distance, method 1 is not significantly different than method 2, method 2 is not significantly different than method 3, and method 3 is significantly more accurate than method 1. Mean differences and *P* values are also noted in Table 3.

Discussion

Although other appropriate distances for the placement of the models could have been chosen, we determined the distance from the bucky by using the measurement of one of the authors who at a height of

179 cm and weight of 70 kg had a pelvic width measurement of 34 cm. Therefore, a 17-cm placement of our model from the bucky was determined to be a reasonable distance. Five millimeters of slippage for the modeled retrolisthesis was chosen because it exceeds the 3 mm Iguchi¹⁷ uses to determine retrolisthesis and falls within the range of clinical findings. In addition, if the measured retrolisthesis on the radiographs was less than the model's true amount (5 mm), there would still be a margin of 2 mm to stay within Iguchi's definition of 3-mm slippage indicating retrolisthesis.

As the use of line drawing to analyze radiographs is a common practice in some offices, it is important to investigate these methods, as it has been repeatedly shown that sources of measurement error, such as vertebral shape and positioning, may affect the accuracy of such measurements.^{8–14} Given the difficulty in clearly choosing the intended marking points involved in measurement, we lost confidence in the

Table 2 The Amount of Retrolisthesis Error in the Measurement of the Radiographs Compared With the Calculated (Expected) Projected Retrolisthesis Size That Should Have Been Found on the Radiographs

Rotation	Method 1 (40 in)	Method 2 (40 in)	Method 3 (40 in)	Method 1 (84 in)	Method 2 (84 in)	Method 3 (84 in)
0 rotation	1.9 mm	*−0.1 mm	0.9 mm	1.5 mm	1.5 mm	1.5 mm
−5°	1.4 mm	0.4 mm	0.9 mm	2.0 mm	1.0 mm	1.0 mm
−10°	1.4 mm	1.4 mm	0.4 mm	2.6 mm	2.6 mm	1.1 mm
+5°	1.4 mm	0.4 mm	0.4 mm	0.5 mm	0.5 mm	0.5 mm
+10°	1.5 mm	0.5 mm	0.5 mm	1.1 mm	0.6 mm	0.6 mm
Mean	1.5	0.5	0.6	1.5	1.2	0.9
Standard Deviation	0.2	0.5	0.3	0.8	0.9	0.4

The calculated (expected) projected retrolisthesis sizes were 6.1 mm for 0°, 5°, and −10° of rotation at 40-in focal film distance, 6.0 mm for +10° of rotation at 40-in focal film distance with 5.5, 5.5, and 5.4 mm, respectively for 0°, 5°, and 10° of rotation at 84-in focal film distance. In all cases, the measured retrolisthesis size is greater than the calculated projected retrolisthesis size except for method 2 at 0 rotation and 40 in where it is smaller*.

Table 3 Comparison of Measurement Error Using Methods 1, 2, and 3 Relative to Expected Projected Retrolisthesis (Reported in Table 2)

40 inches	Difference of Means	P Value	Result
Method 1 vs method 2 (40")	$1.52 - 0.52 = 1.00$	.02	Method 2 is significantly more accurate than method 1.
Method 2 vs method 3 (40")	$0.62 - 0.52 = 0.10$	.39	Method 2 is not significantly different than method 3.
Method 1 vs method 3 (40")	$1.52 - 0.62 = 0.90$	.00	Method 3 is significantly more accurate than method 1.
84 inches	Difference of Means	P Value	Result
Method 1 vs method 2 (84")	$1.54 - 1.24 = 0.30$	.11	Method 1 is not significantly different than method 2.
Method 2 vs method 3 (84")	$1.24 - 0.94 = 0.30$	.19	Method 2 is not significantly different than method 3.
Method 1 vs method 3 (84")	$1.54 - 0.94 = 0.60$	.05	Method 3 is significantly more accurate than method 1.

ability to measure retrolisthesis where the models were rotated in excess of 10° . This finding is consistent with that of Coleman et al,¹² who noted increasing difficulty in placing best fit measurement lines on their projected computer models as y-axis rotation increased. Because of the lack of confidence to accurately mark the radiographs when models were rotated 20° , none of those radiographs were analyzed and were therefore not included in the study. During the measurement process, some of the radiographs rotated to 15° were deemed to be analyzable, whereas others were not. Our experience in this study suggests that meaningful data cannot be obtained by the clinician at 15° and 20° of rotation. In a clinical setting where there is less control over conditions, coupled with the decrease in image clarity due to scatter of the x-ray beam caused by the mass of the patient, clinicians should strive to avoid measurement of retrolisthesis in vertebrae that are rotated more than 10° . Because of this, models measured with 15° of rotation were included in Table 1 to illustrate the large variance in the measurements at that degree of rotation but omitted from Table 2.

The errors relative to the calculated projected retrolisthesis shown in Table 2 were lower for methods 2 and 3 at the 40-in focal film distance. One possible explanation is that greater magnification of the vertebral models (due to the shorter focal film distance) improved the ability to accurately select the points needed for analysis. This is in keeping with a previous study that noted that, when using a computer model, the ability of the computer to increase the size of the vertebrae facilitated the placement of measurement lines.¹² It should also be noted that the amount of the calculated projection shown in Table 2 varies slightly for different degrees of y-axis rotation of the models. This is due to the fact that, whereas the retrolisthesis is perpendicular to the x-ray beam at 0° rotation, it moves out of that 90° angle by 5° , 10° , 15° , and finally 20° as the models are rotated on the y-axis. If the models were

rotated 90° , the projected retrolisthesis would be zero. There is also a minute difference in the projected retrolisthesis length caused by moving the retrolisthesis closer or further from the tube or film during the y-axis rotation. These 2 factors combine to give a slight difference in the calculated projected retrolisthesis magnitude during varying degrees of y-axis rotation.

Although some authors have indicated that patient positioning is repeatable,^{18–20} errors in positioning can obviously be made in a clinical setting. Although it is not the purpose of this article to evaluate methods that might be used to determine if y-axis rotation has occurred as a result of patient placement or from segmental y-axis rotation, awareness of y-axis rotation in patient placement is important to the clinician who seeks to measure retrolisthesis. Fortunately, there appear to be at least 2 methods that would indicate if the lumbar vertebrae being studied had undergone y-axis rotation due to patient placement or other factors and to compare the amount of rotation found on different lateral radiographs. The easier of the two would involve comparing the photographs of the radiographs in this article to the radiographs of the vertebrae being analyzed (Figs 2–6). This would allow a general estimate of the amount of rotation present on the clinician's radiograph. A second method is to measure the distance between femurs on the anterior-posterior (A-P) view and then measuring the distance between femurs on the lateral radiograph. By using the following calculations, the clinician can have a more accurate assessment of the number of degrees of rotation of the patient.

Fig 12 shows the triangular representation of the angles and lengths involved in the A-P film calculations to find the actual widths of the distance between the femur heads, given zero y-axis rotation and a measurement of 19 cm between the top dead center of each femur head on the A-P film at 84" FFD and 4" object (femur heads) to film distance. For the purpose

of this example, we used author M.L.'s measurements taken from radiographs that had been exposed in the process of M.L. receiving chiropractic care.

Using trigonometric ratios from the earlier examples to determine the angle B given the known values of sides a and b and angle C at 84° FFD, we then applied the known values of angle B and the shorter length of 80" (subtracting 4" for object film distance of subject M.L.'s size) to determine the actual width from the center of L4-5 to one femur head ("b") as opposed to the radiographic measurement of that distance to the femur head. We applied this "b" value (using the Law of Cosines, Law of Sines, and trigonometric ratios described earlier) to determine the next value of "b" representing the measurement on the lateral film, which led to the eventual value of "X" (Fig 13). Where "X" (2 times "b" at the film) is the distance between the top dead centers of the femur heads measured on the lateral film, when visible displacement is evident because of y-axis rotation of the subject on the lateral radiograph.

To answer the question "how much displacement between the femur heads is visible on the lateral radiograph with either 5° or 10° y-axis rotation positioning error," additional calculations are needed. This sample calculation uses M.L.'s radiograph and assumes that the center of y-axis rotation is at the center of the posterior aspect of the L5 vertebral body. Fig 14 shows the triangular representation of the femur head displacement ("X" on Fig 13) on the lateral film with 5° or 10° y-axis rotation and the angles and lengths involved in these calculations with subject M.L.'s measurements given above.

The Law of Sines ($\sin B/b = \sin C/c$) is used to determine the angle B for an 84" FFD. We then applied the known variables of a, b, and angle B to trigonometric ratios and determined the measured displacement of the femur heads on the lateral film with 5° and 10° y-axis rotations of L4-5 as used in our models ("X" = 2b). Therefore, if we know that the A-P film was taken

Fig 13. Representation of a lateral radiograph, showing the images of 2 femur heads offset because of rotation of the subject at the time of the exposure. "X" is the measured distance on the film between the top dead centers of the offset femur heads' projected images.

without significant y-axis rotation (the pubic symphysis aligns with S2) and we also know the size of the patient to determine the object film distance (in this case, 4" from femur heads to film on the A-P using subject M.L.), we can compute what 5° or 10° of y-axis rotation at L4-5 would do to the measurement found on the lateral film between femur heads. Using our subject M.L., these results indicate that an "X" value of 17 mm indicates a y-axis rotation of 5° and 34 mm indicates 10°.

This second method does not take into account the rotation of the vertebrae being studied relative to the femurs, but any significant rotations of the bony structures can be observed on the A-P view and used as an additional consideration by the clinician. Furthermore, if the visual comparison method of the vertebrae on the lateral radiograph showed rotation but the femur measurement showed no rotation, the clinician might conclude that the vertebral rotation

Fig 12. Representation of the A-P pelvic radiograph as viewed from above. Angle "B" is the divergence of rays: "c" from the x-ray source through the top dead center of the femur head to the film on one side and "a" from the x-ray source through the center of the nonrotated L4-5 vertebra model to the film on the other side. The x-axis of the pelvis is parallel to the film. Side "b" is the distance from one femur head to the center of the vertebra at L4-5. Ray "a" is the focal film distance of 84" (213.36 cm). The measured distance on the film between the top dead center of the projected images of the 2 femur heads is represented by "x" (19 cm in our example).

Fig 14. Representation of the lateral radiograph of a malpositioned patient as seen from above. Rays “a” and “c” pass through the center of the femur heads. Angle “B” is the angle formed between ray “c” and the central ray. “X” is the projected distance between the femur heads, whereas “b” is the actual distance between the femur heads. Angle “A” is the angle between ray “c” and the line between the femur heads. “C” represents the vertebral model.

was not the result of patient placement but had to do with other factors producing y-axis rotation in the spine. As it was not the purpose of this article to investigate methods to improve patient placement or to evaluate the placement errors that occur in clinical practice and those investigations are beyond the scope of this article, we hope that others will conduct additional studies of this subject.

Method 1 has been previously studied and found to have excellent inter- and intraexaminer reliability.⁷ There is also reason to believe that method 2 may have a reasonable degree of reliability. The Meyerding’s method of grading spondylolisthesis, which has been shown to have excellent inter- and intraexaminer reliability, is essentially the mirror image to method 2, with the obvious difference that Meyerding’s method assesses relative anterolisthesis of the vertebral bodies as opposed to the assessment of retrolisthesis.¹ Method 3 has not been tested for reliability. In this experiment, the values for method 3 were at least as accurate or more so for most of the measurements as the other 2 methods. It should be noted that this is not evidence of method 3’s reliability.

In addition to being a part of the measurement process used by some chiropractic clinicians, retrolisthesis has been associated with low back pain, abnormal myographic findings in the paraspinal muscles, increased spinal bone density, and worse postoperative outcomes following lumbar disk surgery.^{5,21–25} However, those measuring retrolisthesis should be aware that there are limitations to the accuracy of measurement procedures and be cognizant of the inherent inaccuracies before using any particular measurement method. This article is one among many which have looked at the various sources of error plaguing those who seek to make accurate measurement of structures on radiographs.^{8–14} An interesting field of future study might involve the determination of the percentage of clinicians who are concerned about the accuracy of methods used to measure bony alignment and what steps, if any, they take to reduce their errors.

Although it is obvious that very large amounts of retrolisthesis would render a spine unstable, the amount of retrolisthesis that may be clinically significant is unknown. Before a discussion of clinical significance can be held, it is necessary to establish the accuracy of measurement methods. Otherwise, clinicians will not be able to differentiate between real retrolisthesis and measurement or projection error. If clinicians have a sense of the expected error of their measurement method, they can simply measure the projected level of retrolisthesis; subtract the expected error rate; and, if this value is greater than their clinical definition of retrolisthesis, they can be confident in their finding. This issue especially reflects on the foundations of chiropractic techniques like the Gonstead Method, which hypothesizes that delivering “specific” chiropractic adjustments to correct relatively small biomechanical problems that a clinician has determined to be subluxations is superior to other forms of manipulation that are not intended to correct spinal misalignments. Although one would think, after more than 100 years of many in the chiropractic profession having supported the importance of correcting misalignments, that “a very large number of long term, large-scale studies supporting the importance of correcting misalignment with chiropractic care and tying such correction to significant improvements in patients’ long-term health and well-being would litter the PubMed literature,” this is not the case.² As leaders in this field, chiropractors should be the ones to determine the value, if any, of correcting relatively small spinal misalignments. But before these types of studies can be accomplished, the limitations of measurement methods must be firmly established.

There are a number of points at which error may occur in a study such as this, and steps were taken to attempt to reduce their effect. Because of concerns about the accuracy of the tools used to make measurements, we chose a Pickett Model 6180 protractor mounted to the turntable to record the amount of rotation of the models;

and the accuracy of our ruler was checked by comparing it with other rulers. Although it was easier to accurately rotate our models than it would have been an x-ray phantom or an actual patient, we recognized that there was still the potential for error and the Pickett protractor was essential in that process.

The vertebral models themselves could also lead to changes in projection. Vertebrae are 3-dimensional objects; and although our selected models showed no apparent anomalies and were visually symmetrical, there is not perfect symmetry in nature, and it has been shown that small changes in shape can create measurable changes in the projected image.¹⁰

It is more difficult to position a 3-dimensional object in retrolisthesis than a 2-dimensional one; therefore, error may have been produced in positioning the models to create the 5-mm retrolisthesis. Recognizing this potential source of error, we sought to improve positioning accuracy by marking the point on the bottom of the fourth lumbar vertebral body where the posterior superior border of the fifth lumbar vertebral body needed to be positioned to obtain the desired 5 mm of retrolisthesis. Yet, it cannot be ruled out that these types of error sources combined with measurement error may have been responsible for the finding that all except one of the measurements were greater than the amount that we mathematically calculated should have been found on the radiograph. It should also be noted that, although any errors in the positioning of our vertebral models to obtain a 5-mm retrolisthesis are important to this study, they would not be a consideration in clinical practice where the magnitude of the retrolisthesis would be the factor the clinician wished to evaluate.

We needed to identify a number of points on the radiograph to perform our analysis. Identifying these points became more difficult for the author making the measurements as the amounts of rotation increased. To improve accuracy, we used a doctor of chiropractic who both had experience in the clinical use of radiographic analysis and had analyzed radiographs for previous studies. In addition, it was determined that this person would not analyze any radiograph where he did not feel that he could locate the points needed for analysis with reasonable certainty.

As we noted previously, in a clinical setting where there is less control over conditions coupled with a decrease in image clarity due to the scatter radiation caused by the mass of the patient, the clinician may have even more difficulty obtaining accurate measurements than we did in this study. This prompts our recommendation that clinicians consider avoiding

measurement of retrolisthesis in vertebrae that have undergone more than 10° of y-axis rotation. This is in keeping with the finding of Coleman et al¹² of a decreased accuracy in the ability to measure angulations between adjacent vertebral end plates using computer models in the A-P view when the models were rotated 14°.

Measurement of radiographs is a frequently used procedure. But meaningful studies testing the effects of spinal misalignment on patient health or changes to patient conditions that might be brought about by improving alignment cannot take place without a thorough understanding of all the factors affecting the accuracy of measurement methods. In addition, *The Textbook of Clinical Chiropractic*, which is the most commonly used text to teach the Gonstead Method, discusses both the radiographic evaluation of retrolisthesis and its effect on the size of the intervertebral foramen.^{5,26} The text indicates that, because of its z-axis movement, retrolisthesis has a marked effect on the contents of the intervertebral foramen and demonstrates an adjustment procedure for this problem.^{26,27} As the Gonstead technique is used in some form by more than half the practicing doctors of chiropractic³ and as other chiropractic and medical clinicians may also use the evaluation of retrolisthesis in their practices, it is important to determine the accuracy of measurement methods for retrolisthesis because patient care could be based on inaccurate measurements of this common condition. Therefore, studies such as this are necessary as a step toward a better understanding of the accuracy of retrolisthesis measurement methods.

This study assesses different methods of lumbar retrolisthesis measurement in the presence of radiographic distortion created by y-axis rotation and also calculates the amount of change that y-axis rotation at different focal film distances causes in projected retrolisthesis magnitude. Common conditions such as scoliosis and lateral listhesis create relatively large amounts of y-axis rotation that may confound radiographic evidence of lumbar retrolisthesis. This can be compounded by errors in patient placement and inexact x-ray machine alignment.¹⁴ Retrolisthesis assessment may be hindered by such distortions. The evidence of this exploratory study supports the likelihood that 2 of these methods tested (methods 2 and 3) may be more accurate in lumbar retrolisthesis measurement than the other (method 1). This study is a step towards further experiments to test the reliability and validity of this type of measurement procedure that is used by some chiropractic physicians. Just as there are numerous studies on the effects of manipulation on low back pain,

there is a need for multiple studies regarding the use of imaging to evaluate retrolisthesis. We recommend that further studies be conducted to further determine the value or lack thereof of these measurements. These studies might involve data from multiple chiropractic physicians in a clinical setting using a larger data set and methods 2 and 3 and should consider both actual vertebral movement and its effect on the predicted projections on the radiograph.

This study reinforces the need for proper patient placement when performing radiographic studies and highlights a number of the issues that should be considered in larger and more comprehensive studies. It also looks at the difference between the actual amount of retrolisthesis that is present and the projected magnitude that should be found on the radiograph at varying degrees of y-axis rotation, reinforcing the sometimes clinically overlooked fact that the radiograph is a projection rather than a picture. The results should prompt a consideration of the limitations present when attempting to measure retrolisthesis and encourage others to further investigate this and other measurement methods. Given the exploratory nature of this study, it is important to view the findings as suggestive rather than definitive.

Limitations

There are a number of limitations to this study. Only 1 vertebral model was used. The radiographs were only measured once at each rotation and focal film distance and only by one person. We have previously noted the supporting factors for method 2, but it has not been proven to be reliable. The reliability of method 3 has not been established either. Finally, this is an exploratory study; and the number of methods we investigated was limited to three that are used to measure retrolisthesis. However, we recognize that other methods such as the Van Akkerveeken's Measurement of Lumbar Instability could be included in future projects. Given the exploratory nature of this study and the noted limitations, it is important to view the results as suggestive rather than definitive.

Conclusions

The findings of this study suggest that either method 2 or method 3 will generally provide smaller errors than method 1 when measuring retrolisthesis. Results also

suggest that attempts to measure retrolisthesis beyond 10° of rotation may not be reliable.

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References

1. Timon SJ, Gardner MJ, Wanich T, et al. Not all spondylolisthesis grading instruments are reliable. *Clin Orthop Relat Res* 2005;434:157–62.
2. Coleman RR, Wolf KH, Lopes MA, Coleman JM. The controversy over chiropractic spinography. *Chiropr Hist* 2013;33:66–81.
3. Cooperstein R. Gonstead chiropractic technique (GCT). *J Chiropr Med* 2003;2:16–24.
4. Haas M, Taylor JA, Gillette RG. The routine use of radiographic spinal displacement analysis: a dissent. *J Manipulative Physiol Ther* 1999;22:254–9.
5. Rowe SH. Plain film radiography in chiropractic. In: Plaugher G, editor. *Textbook of clinical chiropractic: a specific biomechanical approach*. Baltimore: Williams & Wilkins; 1993. p. 131–2.
6. Gohl RA. *Clinical biomechanical spinal analysis*. Glendale: Gohl Publishing; 1997.
7. Plaugher G, Cremata EE, Phillips RB. A retrospective consecutive case analysis of pretreatment and comparative static radiological parameters following chiropractic adjustments. *J Manipulative Physiol Ther* 1990;13:498–506.
8. Weinert DJ. Influence of axial rotation on chiropractic pelvic radiographic analysis. *J Manipulative Physiol Ther* 2005;28:117–21.
9. Dulhanty JA. A mechanical and graphical evaluation of the Gonstead pelvic radiographic analysis. *Chiropr J Aust* 1997;27:98–110.
10. Coleman RR, Bernard BB, Harrison DE. The effects of x-axis vertebral translation on projected y-axis vertebral rotation. *J Manipulative Physiol Ther* 1998;21:333–40.
11. Coleman RR, Bernard BB, Harrison DE. Correlation and quantification of projected 2-dimensional radiographic images with actual 3-dimensional y-axis vertebral rotation. *J Manipulative Physiol Ther* 1999;22:21–5.
12. Coleman R, Harrison D, Fischer T, Harrison SO. Correlation and quantification of relative 2-dimensional projected vertebral endplate z-axis rotations with 3-dimensional y-axis vertebral rotation and focal spot elevations. *J Manipulative Physiol Ther* 2000;23:414–9.

13. Coleman RR, Harrison DE, Bernard BB. The effects of combined x-axis translation and y-axis rotations on projected lamina junction offset. *J Manipulative Physiol Ther* 2001;24:509–13.
14. Wall MS, Oppenheim WL. Measurement error of spondylolisthesis as a function of radiographic beam angle. *J Pediatr Orthop* 1995;15:193–8.
15. Mehta JS, Kochhar S, Harding IJ. A slip above a slip: retrolisthesis of the motion segment above a spondylolytic spondylolisthesis. *Eur Spine J* 2012;21:2128–33.
16. Henson J, McCall IW, O'Brien JP. Disc damage above a spondylolisthesis. *Br J Radiol* 1987;60:69–72.
17. Iguchi T, Wakami T, Kurihara A, Kasahara K, Yoshiya S, Nishida K. Lumbar multilevel degenerative spondylolisthesis: radiological evaluation and factors related to anterolisthesis and retrolisthesis. *J Spinal Disord Tech* 2002;15:93–9.
18. Gadotti IC, Magee D. Assessment of intrasubject reliability of radiographic craniocervical posture of asymptomatic female subjects. *J Manipulative Physiol Ther* 2013;36:27–32.
19. Plaugher G, Hendricks AD, Doble RW, Bachman TR, Araghi HJ, Hoffart VM. The reliability of patient positioning for evaluating static radiologic parameters of the human pelvis. *J Manipulative Physiol Ther* 1993;16:517–22.
20. Harrison DE, Harrison DD, Colloca CH, Betz J, Janik TJ, Holland B. Reproducibility over time of posture, radiograph positioning, and radiograph line drawing: an analysis of six control groups. *J Manipulative Physiol Ther* 2003;26:87–98.
21. Vogt MT, Rubin DA, Plaermo L, et al. Lumbar spine listhesis in older African American women. *Spine J* 2003;3:255–61.
22. Vogt MT, Rubin D, Valentin RS, et al. Lumbar olisthesis and lower back symptoms in elderly white women. *Spine* 1996;23:2640–7.
23. Sihvonen T, Lindgren KA, Airaksinen O, Manninen H. Movement disturbances of the lumbar spine and abnormal back muscle electromyographic findings in recurrent low back pain. *Spine* 1997;22:289–95.
24. Vogt MT, Rubin DA, Valentin RS, et al. Degenerative lumbar listhesis and bone mineral density in elderly women, the study of osteoporotic fractures. *Spine* 1999;24:2536–41.
25. Kang KK, Shen MS, Zhao W, Lurie JD, Razi AC. Retrolisthesis and lumbar disc herniation: a postoperative assessment of patient function. *Spine J* 2013;13:367–72.
26. Plaugher G, Lopes MA. Clinical anatomy and biomechanics of the spine. In: Plaugher G, editor. *Textbook of clinical chiropractic: a specific biomechanical approach*. Baltimore: Williams & Wilkins; 1993. p. 25.
27. Plaugher G. Lumbar spine. In: Plaugher G, editor. *Textbook of clinical chiropractic: a specific biomechanical approach*. Baltimore: Williams & Wilkins; 1993. p. 237.