A Proposed Mathematical Method to Quantify *y*-Axis Pelvic Rotation on the Anteroposterior Radiograph

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Abstract

Objective: Researchers have identified potential errors in the Gonstead method's analysis of pelvic alignment resulting from *y*-axis rotation of the pelvis on the anteroposterior (A-P) radiograph. The purpose of this article is to propose a method that can be used to determine the magnitude of *y*-axis rotation of the pelvis present on the A-P radiograph.
Methods: In this proposed method, measurements are obtained from the patient and from the lateral and A-P radiographs. With a mathematical method, these measurements are used with the focal film distance to calculate the degree of pelvic rotation present on an individual A-P radiograph.
Results: This method may help with the accuracy of measurement of pelvic *y*-axis rotation on the A-P radiograph.
Conclusion: The method proposed can be used to calculate the magnitude of pelvic *y*-axis rotation on an A-P radiograph. (J Chiropr Med 2017;16:204-210)
Key Indexing Terms: *Radiography; Chiropractic*

Introduction

The image produced by a radiograph is not a picture but a projection and is subject to many distortions. This concept is recognized within the chiropractic community and has been the subject of much discussion. It is understood that vertebral rotation can produce projection distortion that may result in errors in spinal analysis.[1-3] These image distortions affect not only spinal vertebrae, but also the pelvis and its measurement analysis. Researchers have identified potential errors in the Gonstead analysis of pelvic alignment.[4-6] Schram et al stated, "Postural changes can introduce significant errors in pelvic spinography x-ray analysis."[5] Weinert discussed areas of error in the Gonstead pelvic analysis of the anteroposterior (A-P) radiograph and correlated and quantified the errors produced by axial (*y*-axis) rotation in a single pelvic model.[6] Some chiropractic clinicians utilize portions of the Gonstead method in their practices.[7] For those who use the Gonstead method of pelvic analysis, the errors produced by *y*-axis rotation can be important.

At present, there is no method used by Gonstead practitioners that accounts for the distortion of pelvic rotation. The purpose of this article is to propose a method to determine the degree of axial pelvic rotation that has occurred because of patient positioning on the A-P radiograph. This method explores the effect that different axes of rotation within the pelvis may have on calculations for determining *y*-axis rotation of the pelvis and presents methods of analysis.

Methods

With measurements obtained from the patient, the focal film distance, and A-P and lateral radiographs of the pelvis, the clinician can calculate pelvic *y*-axis rotation on the A-P radiograph. The image on the radiograph is magnified; therefore, a portion of the analysis necessitates determining the amount of magnification that has occurred in some of the areas utilized for the calculations.

Lateral Lumbopelvic Radiographic Computations

For this example, the focal film distance will be 72 in. A process was used to calculate the magnitude of magnification on the lateral radiograph.

The distance from the midpoint between the junctions of the patient's right and left lamina to the sacrum at the second sacral tubercle (S2) to the film, with the patient standing in position for the lateral lumbopelvic radiograph, was determined. This

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can be done through the use of calipers or another measuring device. For this example, the distance is 5 in. Therefore, the source–object (tube to patient) distance is 72 in – 5 in = 67 in, and the object–film distance is 5 in.

On the lateral lumbopelvic radiograph, a dot was placed at the top center of each femur head. A vertical line was erected above each dot. The 2 parallel vertical lines were connected with a horizontal line. Finally, a third dot was placed on the horizontal line halfway between the first 2 dots. This point halfway between the femur heads is termed the *midpoint between the femur heads* (MFH).

A vertical line was erected above MFH. A second vertical line was erected above S2 at the junction of the lamina to the sacrum.

The 2 vertical lines were connected with a horizontal line and determine the length of that line. For this example, the length of that line will be 100 mm (Fig 1).

Using the formula to determine the geometric magnification of an object on a radiograph, the magnification of the length of that projected line as it appears on the radiograph was calculated as

$$M = (a + b)/a$$

where M is the amount of magnification, a is the source (X-ray tube)–object distance (the distance of both S2 and MFH to the tube, which is 67 in), and b is the distance of the object to the film (the distance of both S2 and MFH, which is 5 in). Thus, M = (67 + 5)/67 = 1.07. This is the magnification factor, the amount of magnification of the length of the horizontal distance between MFH and S2 on the lateral radiograph.

For this example, the projected length of the horizontal line from MFH to S2 is 100 mm.

As 100 mm is the length of the projected line on the radiograph and the length of that line is magnified by 1.07, we divide 100 mm by 1.07 to obtain the true horizontal distance between MFH and S2: 93.5 mm.

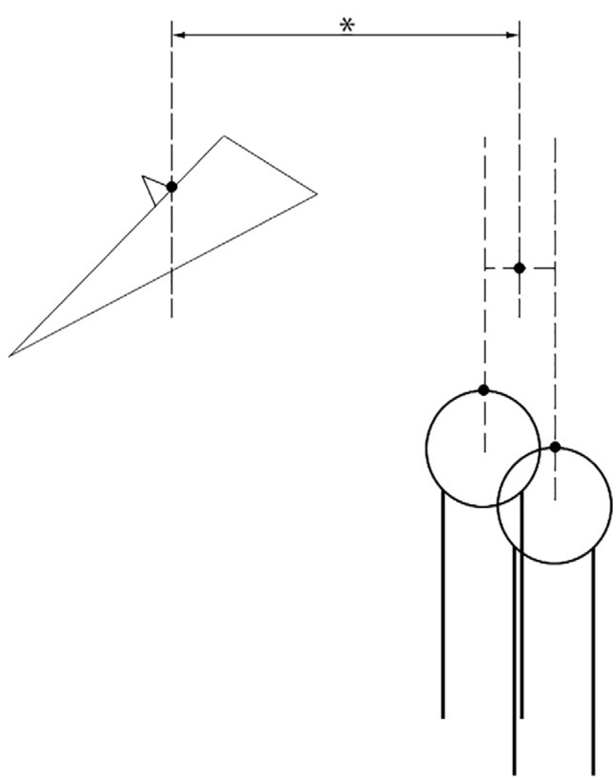

Fig 1. *Lateral radiograph. A vertical line was erected through the second sacral tubercle (S2) at the point where the lamina meets the sacrum. Vertical lines were erected above the center of each femur head and connected by a horizontal line. Another vertical line was erected through the midpoint of this horizontal line, which was the location of the midpoint between the femur heads (MFH). The distance on the* z*-axis between S2 and MFH on the lateral lumbopelvic radiograph is represented by the asterisk and horizontal line connecting the vertical lines that pass through S2 and MFH.*

A-P Radiographic Computations

With the patient standing in position for the A-P radiograph, the distance was determined from the patient's S2 to the film. For our example, that distance is 4 in. As the distance from S2 to the film in this example is 4 in, we add 93.5 mm (the true horizontal distance from S2 to MFH on the lateral view) to the 4-in distance from S2 to the film. This is the true distance from the film to MFH when the patient is positioned for the A-P radiograph.

A dot was placed on the center of the top of each femur head on the A-P radiograph, and these 2 points were connected with a line. A dot was placed on this line halfway between the 2 femur heads (the location of MFH), and a line perpendicular to this line that passes through MFH was erected.

A line that passes through S2 and is parallel to the line that passes through MFH was erected.

The horizontal offset was measured on the radiograph between the lines that pass through S2 and MFH (Fig 2).

Calculating the Pelvic Rotation

When the pelvis rotates on the *y*-axis, different points can serve as an axis of rotation. For the practical clinical application being discussed here, 2 points were used. These points are located at S2 and MFH. The effect that these 2 different axes of rotation have on calculations of the degree of *y*-axis rotation of the pelvis present on the A-P radiograph can then be determined (Fig 3).

Use of S2 as the Axis of Rotation for the Pelvis

If the pelvis is rotated on the *y*-axis, then the line erected through MFH will not be superimposed on the line erected through S2 on the A-P radiograph. For this example of

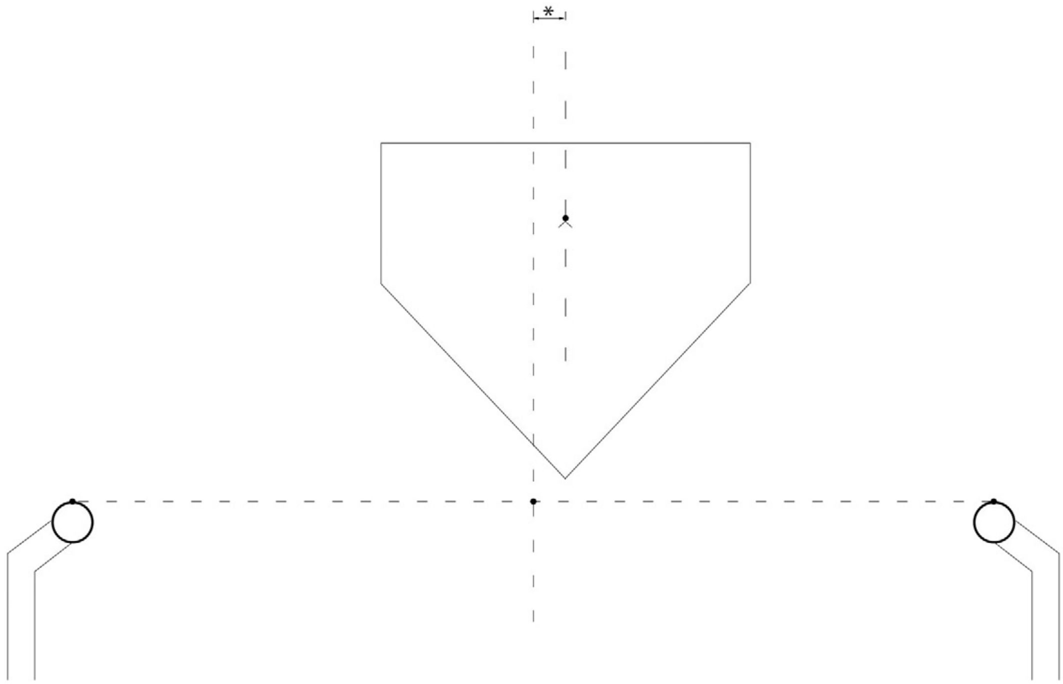

Fig 2. *Anteroposterior radiograph. A line connects the tops of the femur heads. A line was erected perpendicular to that line such that it passes through the midpoint between the femur heads. Parallel to that line is a line passing through the second sacral tubercle. The distance between these 2 lines is shown on the radiograph, as indicated by the asterisk.*

y-axis rotation-induced image distortion, there will be a 10-mm offset between those lines on the radiograph. For an axis of rotation at S2, S2 will be located on the central ray. Therefore, S2 is the reference point/axis of rotation relative to MFH for this measurement. As the pelvis rotates, using this axis, MFH moves off the central ray and creates an offset to S2 on the A-P radiograph (Fig 4).

The distance of the second sacral segment from the film on the A-P radiograph had already been set as 4 in, as has the 72-in focal film distance. By use of the magnification formula $M = (a + b)/a$, a is the source–object distance (in this case, the distance from the tube to MFH); b (distance from MFH to the film) is the distance from the second sacral segment to the film (4 in = 101.6 mm in this example); and

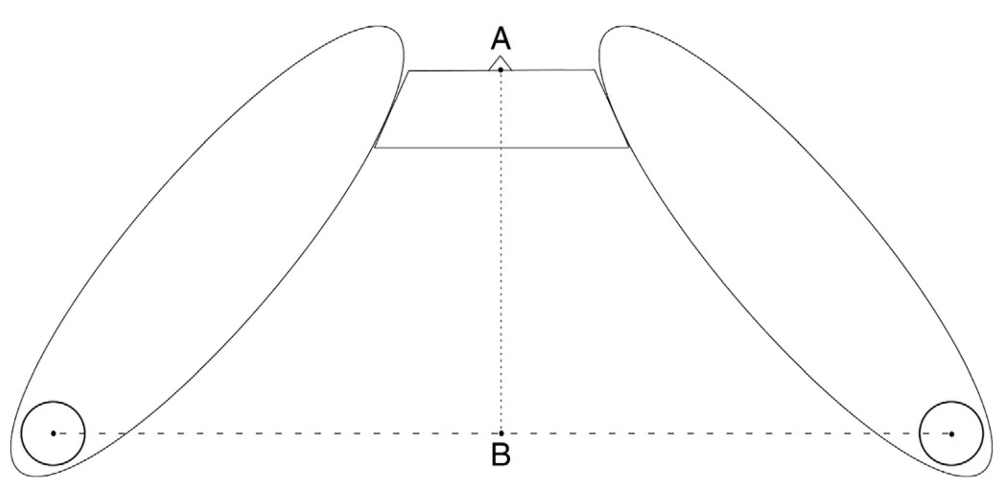

Fig 3. *Superior to inferior view. The tops of the ilia and the sacrum are shown. A line connects the centers of the tops of the femur heads. The second sacral tubercle (S2) (A) was connected to the midpoint between the femur heads (MFH) (B) by a line whose length is the distance between S2 and MFH on the central ray.*

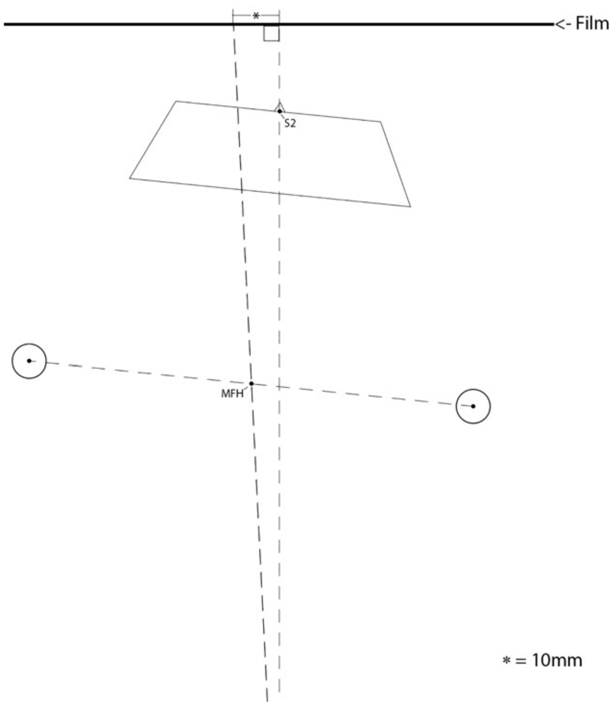

Fig 4. *Superior to inferior view. The top of the sacrum and the tops of the femur heads are shown. The tops of the femur heads were connected by a line in the middle of which is the midpoint between the femur heads (MFH). The pelvis was rotated on the* y*-axis, with the axis of rotation being at the second sacral tubercle (S2). The central ray passes through S2. A ray of the X-ray beam passes through MFH. The distance between the projected S2 and MFH is shown on the film.*

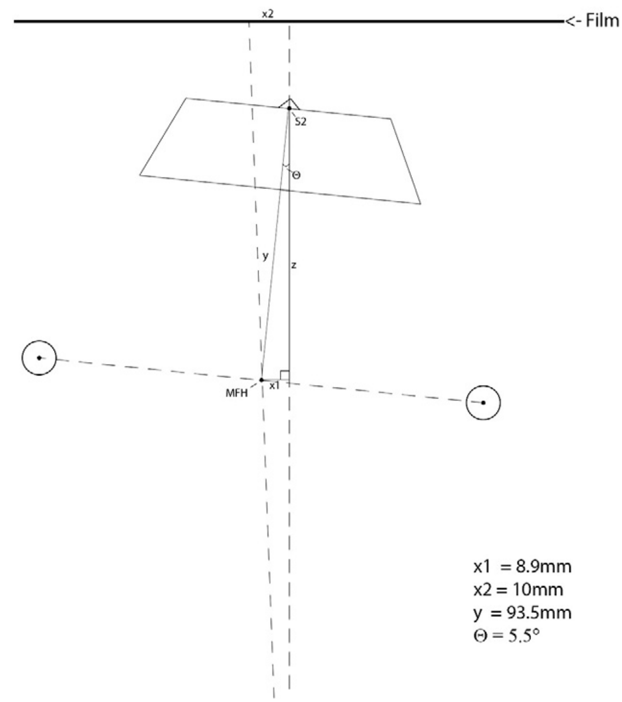

Fig 5. *Superior to inferior view. Another figure illustrating rotation on the second sacral tubercle (S2) axis. The central ray passes through S2, and another ray of the X-ray beam passes through the midpoint between the femur heads (MFH). x1 was the true offset between S2 and MFH. x2 was the projected offset between S2 and MFH on the radiograph. The length of* y *is the true distance between S2 and MFH when both are on the central ray, and its length is calculated from the lateral view. The z side is not used in calculating the pelvic rotation. It will always be shorter than the true distance between S2 and MFH when both are on the central ray.*

the horizontal distance between S2 and MFH on the lateral view has already been determined to be 93.5 mm.

Therefore,

$$b = 101.6\ \text{mm} + 93.5\ \text{mm} = 195.1\ \text{mm}$$

The 72-in focal film distance in millimeters is 1828.8 mm. Therefore, to solve for a,

$$\begin{aligned} a &= 1828.8\ \text{mm} - 195.1\ \text{mm} = 1633.7\ \text{mm} \\ &\quad (\text{total distance from X-ray tube to MFH}) \\ a + b &= 1633.7\ \text{mm} + 195.1\ \text{mm} = 1828.8\ \text{mm} \\ M &= (a+b)/a = 1828.8\ \text{mm}/1633.7\ \text{mm} \\ &= 1.12\ \text{magnification factor} \end{aligned}$$

To calculate the projected offset of MFH to S2, we use the parallel lines passing through these 2 points.

To find the true, nonmagnified distance of the MFH to S2 offset, an example of a projected 10-mm offset on the A-P radiograph would be divided by the magnification factor of 1.12: 10 mm/1.12 = 8.9 mm = true offset distance from S2 to MFH.

A right triangle was constructed with the true offset distance of 8.9 mm as one side. The true horizontal distance from MFH to S2, which had already been determined to be 93.5 mm, was the hypotenuse. The angle opposite the 8.9-mm side was the degree of rotation of the pelvis in this example. This angle was found using the 90° angle, a hypotenuse of 93.5 mm, and the side opposite the angle of pelvic rotation of 8.9 mm (Fig 5). According to the law of sines, sin θ = opposite/hypotenuse.

$$\sin\theta = 8.9/93.5 = 0.095;\quad \theta = \sin^{-1}(0.095) = 5.5^{\circ}$$

Therefore, the rotation of the pelvis using S2 as the axis of rotation is 5.5°.

Use of MFH as the Axis of Rotation for the Pelvis

The second point selected for an axis of rotation is MFH. If the rotation is located at MFH, then the point that moves off of the central ray and produces the offset relative to

MFH, on the A-P radiograph, is S2. Then the following would be true:

$$M = ([72\,\text{in}{-}4\,\text{in for the distance from S2 to the film} = 68\,\text{in}] + [4\,\text{in for the distance from S2 to the film}])/68$$
$$M = 72/68 \text{ or } 1828.8\,\text{mm}/1727.2 = 1.06 \text{ magnification factor}$$

The 10 mm of projected offset divided by 1.06 equals the 9.4-mm true horizontal offset of MFH to S2.

A right triangle was constructed using the true offset distance as one side (9.4 mm) and the true horizontal distance from MFH to S2, which had already been determined to be 93.5 mm, as the hypotenuse. The angle opposite the 9.4-mm side was the degree of rotation of the pelvis in this example. The pelvic rotation angle was again found using the law of sines. Therefore, the amount of pelvic rotation using the MFH as an axis is 5.8°.

$$\sin\theta = \text{opposite}/\text{hypotenuse}$$
$$\sin\theta = 9.4/93.5 = 0.101, \quad \theta = \sin^{-1}(0.101) = 5.8^{\circ}$$

Results

By use of the parameters established for this example, the projected length of the horizontal line from MFH to S2 on the lateral lumbopelvic radiograph was 100 mm, whereas the true horizontal distance between these 2 structures and the distance on the *z*-axis between MFH and S2 when both are on the central ray was 93.5 mm. If S2 had been used as the axis of rotation, the magnification factor would be 1.12. The projected horizontal offset between MFH and S2 on the A-P radiograph was 10 mm, whereas the true offset was 8.9 mm, and the degree of pelvic rotation 5.5°. If MFH had been used as the axis of rotation, the magnification factor would be 1.06, the projected offset of MFH to S2 10 mm, the true offset 9.4 mm, and the degree of pelvic rotation 5.8°.

Discussion

As this proposed mathematical method has been used to quantify *y*-axis pelvic rotation on the A-P radiograph to better understand its effect on Gonstead measurements of the pelvis, it has not been tested for validity, repeatability, or whether it has any effect on clinical outcomes. It provides a clinical tool that, when coupled with present and future research, may improve our understanding of the magnitude of effect that *y*-axis–induced projection distortion has on Gonstead measurements of the pelvis on the A-P radiograph. This tool is designed to be used primarily in a clinical setting and, as such, is not intended to have the exacting accuracy necessary in some scientific applications.

Some practicality has been substituted for exacting calculations in our computations as described below. This practicality does not change the outcome in clinical usage. Two readily apparent inaccuracies deserve mention. Both S2 and MFH cannot be exactly 67 in from the tube on the lateral radiograph. In this case, the 67-in distance is located on the central ray, and both S2 and MFH cannot be located on the central ray at the same time. However, this difference is obviously quite small at our selected source–object distance of 67 in and, as such, will not be explored. The magnitude of the second inaccuracy is not as readily apparent and deserves an explanation.

This method of calculation does not take into account that the distance on the *z*-axis between MFH and S2 decreases during pelvic rotation. For example, when S2 is used as the axis of rotation, MFH moves away from the central ray during pelvic rotation. It also moves toward the film.

Consider 2 lines: one running parallel to the film along the *x*-axis through the S2 segment, and the other parallel to the first, running through MFH. If the pelvis is rotated on the *y*-axis, those 2 lines will move closer to each other on the *z*-plane, as viewed from above. This effectively shortens side *z* shown on the triangle in Figure 5. As pelvic rotation increases, the distance on the *z*-axis between S2 and MFH decreases. The distance between S2 and MFH is used in calculating the magnification factor. However, in the practical application for which it is intended, this magnitude of change in that distance should have little significant effect on the calculations. This can be illustrated by erecting a right triangle in which one angle is 90°, the hypotenuse is the same 93.5 mm from our previous examples, and the degree of pelvic rotation is 10°.

It is then possible to find that the shortened distance on the *z*-axis between S2 and MFH on the central ray, side *z*, is 92.1 mm. This is a change of 1.4 mm from the distance of 93.5 mm that was used as the *z*-axis distance between S2 and MFH in our example. When this change is inserted into the formula, the magnification factor changes from 1828.8/1633.7 = 1.12 in our example to 1828.8/1635.1 = 1.12. It appears that the *z*-axis distance change has little significant effect in up to 10° of pelvic rotation. For clinical use in a mildly rotated pelvis, we have chosen to ignore this change. However, the clinician should be aware that as the degree of pelvic rotation increases, it creates greater changes in these calculations.

The choice of 10° of pelvic rotation in the prior example was not merely arbitrary. In previous projection error-related studies of other areas of the spine, it was found that with increasing degree of rotation, the ability to accurately measure vertebral alignment decreases, with findings in one study suggesting that rotations of more than 10° decreased the accuracy of retrolisthesis measurement.[8,9] Therefore, 10° of pelvic rotation was chosen for this example.

In a clinical setting, it appears that there is little impact no matter which of the 2 discussed axes of rotation is used. It may be possible to increase the accuracy of the measurement slightly by choosing the axis closest to a vertical line that passes through the central ray on the A-P radiograph.

Although the determination of the magnitude of the pelvic rotation is of interest, it only provides the clinician with the degree of pelvic rotation that does or does not exist. This determination is useful in deciding if *y*-axis rotation is likely to have played a significant role in altering the projected images on the A-P radiograph. For that reason alone, this process is a valuable tool. When combined with present and, it is hoped, future research, it may become of further clinical value.

Weinert reported that the Gonstead method analysis of the pelvis on A-P radiographs taken at a 40-in focal film distance with the central ray 2 in below the iliac crests is affected by *y*-axis rotation.[6] The results of that study indicated a difference in changes between like structures, with one side becoming progressively larger and the other side progressively smaller as rotation increases. Those findings led us to believe that such differences have been influenced by the direction of axial rotation, which is another reason that pelvic rotation should be understood.

Weinert noted that the model was a phantom in which the bones were encased in plastic and exact measurement of the bony structures was not possible.[6] The changes found in that study were correlated to each degree of *y*-axis rotation starting in the non-rotated position and proceeding to 10° of rotation. This correlation may give the clinician some idea as to the magnitude of changes expected at different points in axial rotation, especially if the degree of pelvic rotation was small.

Future studies could be performed using focal film distances and central ray positions similar to those used by providers employing Gonstead analysis methods. Coupled with different-sized pelvic models at various object–film distances and degrees of rotation, such future studies could give rise to tables that allow clinicians to better understand the magnitude of change that has occurred in a particular clinical case.

Information that has value in a clinical setting can be derived from radiographs in which the pelvis has undergone *y*-axis rotation, but an understanding of the magnitudes of the inaccuracies that are present as well as the projection factors involved is required. The present study allows clinicians to calculate the magnitude of axial pelvic rotation on A-P radiographs.

This method is intended to be a useful tool and is not intended to achieve the accuracy of measurement necessary in some scientific applications. In addition, it is not intended as a substitute for efforts to position the patient properly. This method is intended for those cases that occur in the real world when, even though the appropriate steps are taken, the radiograph shows some degree of offset between S2 and MFH.

Structural evaluations may be made using standing postural radiographs.[10,11] However, errors in placement can distort pelvic measurements.[12] In a 1987 article, Friberg determined *y*-axis rotation on the A-P radiograph using trigonometry.[10] However, there was no consideration of focal film distance or source–object or object–film distances, and magnification was not calculated. There was also no mention of the shortening of the distance between objects on the *z*-axis on the A-P radiograph during *y*-axis rotation or the effect of using different axes of rotation.

We hope this article continues the movement toward a greater understanding of the magnitude of errors inherent in measurements obtained using spinal radiography. Fortunately, radiographic measurement is only one of many analytical tools used in the clinical setting. But it is a tool that, when used, should be understood. Without consideration of the projection error produced by a badly rotated pelvis, the one thing that can be said concerning bony alignment is that if the structure appears aligned in such a pelvis on the A-P radiograph, it probably is not.

Limitations

This mathematical method of quantification of *y*-axis pelvic rotation on A-P radiographs has been proposed to better understand the effect of such rotation on Gonstead measurements of the pelvis and has not been tested for validity, repeatability, or its effects on any clinical outcomes. We hope to perform future studies of this method in relation to these areas of interest. This study used only one model of a patient, pelvis, and focal film distance. The accuracy of this measurement method includes taking measurements from the patient. Such measurements may become increasingly difficult with increases in body mass index. This method has inherent error as practicality has been favored over exacting accuracy. Further research, such as calculation of inter- and intra-rater reliability, is necessary to determine the accuracy.

Conclusion

Pelvic rotation on the *y*-axis can serve as a confounder to those clinicians utilizing radiographic pelvic analysis, such as those using the Gonstead method. The method proposed in this article is used to calculate the magnitude of pelvic rotation on the A-P radiograph.

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Contributorship Information

Concept development (provided idea for the research): R.R.C., M.A.L., D.A.L.
Design (planned the methods to generate the results): R.R.C., M.A.L., D.A.L.
Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): R.R.C., M.A.L., D.A.L.
Data collection/processing (responsible for experiments, patient management, organization, or reporting data): R.R.C., M.A.L., D.A.L.
Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): R.R.C., M.A.L., D.A.L.
Literature search (performed the literature search): R.R.C.
Writing (responsible for writing a substantive part of the manuscript): R.R.C., M.A.L., D.A.L.
Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): R.R.C., M.A.L., D.A.L.
Other (designed and created the figures): D.A.L. (with the assistance of M.A.L.)

Practical Applications

- This study proposes a method to determine the y-axis rotation of the pelvis on the A-P radiograph.
- The method has the potential to be investigated further to better understand the effect of y-axis pelvic rotation on the radiographic image on the A-P radiograph.

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