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Interrater and Intrarater Reliability in the Measurement of Kyphosis in Postmenopausal Women With Osteoporosis

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Study Design. A reliability study was performed using repeated random measurements involving three observers, 26 subjects and three instruments.

Objectives. To determine the most reliable, cost-effective, noninvasive, and clinically feasible method of measuring spinal kyphosis.

Summary of Background Data. The most clinically useful, noninvasive and reliable method of measuring postural deformity in spinal osteoporosis (kyphosis) remains unqualified. Despite traditional use of costly, invasive roentgenographs for the evaluation of spinal kyphosis, the reliability of this method remains questionable.

Methods. Twenty-six postmenopausal women with known bone mineral density and a diagnosis of osteoporosis were recruited from the Osteoporosis Program at Women's College Hospital, Toronto, Canada. Noninvasive measurements of thoracic kyphosis were obtained by three trained examiners using the DeBrunner's kyphometer and the flexicurve ruler. The intrarater and interrater reliability of and between each method was compared, using roentgenographic films obtained in the sagittal plane. Spinal posture was classified according to the method of Itoi (1990). Statistical computations were performed using SAS statistical software.

Results. Consistent measurements were obtained with the DeBrunner's kyphometer and the flexicurve ruler by each observer, according to the results of critical two-way analysis of variance (Intraclass Correlation Coefficient 2,1). Measurements in two subgroups, healthy backs (n = 11) and rounded backs (n = 13), showed consistent use of each noninvasive instrument with some examiner preference for specific tools. There was marginally better intrarater and interrater reliability using the DeBrunner's kyphometer compared with that obtained with the flexicurve ruler. Two-way analysis of variance (Intraclass Correlation Coefficient 2,1) of collapsed data showed no significant difference in the reliability of the kyphometer, flexicurve ruler, or roentgenographs in the measurement of thoracic kyphosis.

Conclusions. The flexicurve ruler and DeBrunner's kyphometer had the closest agreement in the measurement of spinal kyphosis. The kyphometer demonstrated the least variation in intrarater and interrater reliability when compared with the flexicurve ruler and roentgenographs. The flexicurve ruler permits qualitative assessment of posture, however, and is the most cost-effective instrument. The results of this study challenge the traditional belief that roentgenographic analysis is the best method for evaluating spinal kyphosis. The DeBrunner's kyphometer and flexible ruler may represent viable, cost-effective and noninvasive alternatives to roentgenographic evaluation of spinal kyphosis. [Key words: DeBrunner's kyphometer, flexicurve ruler, kyphosis, osteoporosis, roentgenographs] **Spine 1998;23: 1978–1985**

Postmenopausal women are vulnerable to accelerated and disproportionate loss of cancellous bone in the thoracic and lumbar vertebrae. Structurally weakened bone predisposes these women to fractures which, in turn, cause intense pain and limitation of spinal motion. Pronounced kyphosis of the thoracic spine, commonly referred to as "dowager's hump," is one of the most common clinical manifestations of spinal osteoporosis and is attributed to insufficiency fractures of the affected vertebral bodies[6] and decreased back extensor strength.[20]

Spinal Deformities Associated With Postmenopausal Osteoporosis

In the osteoporotic spine, the fracture or collapse of a vertebral body results in anteriorly wedge-shaped, codfish-shaped, or flat vertebral body deformities[17] that can be viewed in roentgenographs. These deformities develop along planes of stress and pull from the center of gravity of the body, causing a kyphotic or increased forward posture. This curvature is most marked in the thoracic region of the spine where it is more than 40°. Kyphosis is often associated with a round back, a stepwise decline in height, and a protuberant abdomen. Those

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affected are easily fatigued, physically[19] and emotionally.[2] Thoracic kyphosis and the resultant changes in the rib cage are also known to decrease rib mobility and alter respiratory function, decreasing the lung's inspiratory and vital capacities and the lateral expansion of the thoracic cage.[5] Spinal deformities in people with osteoporosis have been characterized by the downward shift of the interference vertebra, hyperlordosis of the lumbar spine (particularly the lumbosacral segments to compensate for increased dorsal kyphosis) and a more upright positioning of the sacrum.[17]

Instruments for Measuring Spinal Kyphosis

Several tools and methods that function noninvasively have been used in the past to measure spinal curvature and motion (Table 1). These tools have their related advantages and limitations, which clinicians must weigh in terms of their accuracy, reliability and feasibility. Noninvasive measurement devices have the disadvantage of limiting the clinician to speculation about what is actually occurring at the individual tissue–structural level, which is, in part, achievable by roentgenographic evaluation—traditionally, the gold standard. The DeBrunner's kyphometer[13] and the surveyor's flexicurve (flexible) ruler [8,12] are two tools commonly used to measure spinal kyphosis, yet no study determining or comparing their reliability and/or feasibility in a postmenopausal osteoporotic population has, to our knowledge, been described. Determination of the most reliable measurement device would permit objective documentation of spinal kyphosis for the purpose of longitudinal measurement of either disease progression or its attenuation with therapeutic intervention.

The purpose of this study was to determine the most clinically feasible and reliable noninvasive instrument for measuring spinal kyphosis in a population of postmenopausal women with osteoporosis. To this end, the interrater and intrarater reliability of measuring spinal kyphosis was determined using the Debrunner's kyphometer and the flexicurve ruler as the selected noninvasive measurement devices. Furthermore, measurement values obtained from these instruments were compared with those obtained from roentgenographic evaluation.

Methods

Subjects. Twenty-six postmenopausal women with known bone mineral density and a diagnosis of osteoporosis were recruited as volunteers from a pool of candidates involved in the physical therapy component of the Osteoporosis Program at Women's College Hospital, Toronto, Canada. Women selected for inclusion in this study were white and postmenopausal with a bone mineral density of the lumbar spine more than 1 standard deviation below that of young healthy subjects as determined by dual-energy x-ray absorptiometry. Those with a history of recent (less than 8 weeks) vertebral compression fractures were excluded from the study. Informed consent for participation was obtained from each volunteer.

Noninvasive Measurement. Three examiners (two physical therapists, one occupational therapist) were trained in the use of the Debrunner's kyphometer and the flexicurve ruler before commencement of the study trials. In each subject, identification of the specific spinal landmarks required for the correct application of the kyphometer and flexicurve ruler were corroborated by the three examiners before independent measurements were obtained. Debrunner's kyphometer has a protractor scale in degrees at the apex of two double, parallel arms, each of which is connected at its base to metal blocks large enough to span two spinous processes. The flexicurve ruler is a malleable band of metal, approximately 60 cm long and covered with plastic. It can be bent in only one plane and retains the shape to which it is bent.

Critical reference points for the measurement of thoracic kyphosis using the DeBrunner's kyphometer included the midpoint between the spinous processes of T2 and T3, and the midpoint between the spinous processes of T11 and T12. Critical reference points for the measurement of thoracic kyphosis using the flexicurve ruler included the midpoint of the C7 spinous process, the apex of the thoracic curve, and the L5–S1 junction. Each reference point along the spine was demarcated using the upper margin of nonmovable skin tape.

Spinal kyphosis in each subject was measured using the DeBrunner's kyphometer (Figure 1) and the flexicurve ruler (Figure 2). Each investigator conducted an independent examination of spinal kyphosis using each instrument in a private examination area. With the spine fully exposed, each subject was instructed to stand without shoes on and with weight equally distributed on both feet. Each subject received identical verbal instructions ("stand up as straight and tall as you can, with your arms hanging at your sides") for both measurement methods. Each subject was independently measured at different times and by different observers who used one of the two instruments based on a randomly selected order that was preassigned by a blinded recorder. Spinal curvature was measured three times per instrument by each examiner. Degrees of kyphosis were read directly from the protractor scale of the DeBrunner's kyphometer. In the case of the flexicurve ruler, the molded shape obtained in the sagittal plane was placed on precoded grid paper. The curvature was traced along the length of the ruler marking the C7 spinous process, the thoracic apex, and the L5–S1 junction. A straight edge was used to join these landmarks to enable the length and width of the thoracic and lumbar curves to be measured. An angle of spinal kyphosis was obtained using the traditional Cobb technique applied to roentgenographs, as described elsewhere.[4] The investigators were blinded to each other's results and did not compare their results between measurements. Results were collated by an external, blinded recorder. Qualitative classification of spinal posture was evaluated on the basis of the flexicurve ruler results.

Roentgenographs. A lateral view of the thoracolumbar spine was obtained with the subject in standing position. A second roentgenograph was taken in 50% of randomly selected subjects. Each subject was instructed to "stand as straight and tall as possible" with the hands lightly clasped around an intravenous stand to enable a clear lateral view of the thoracic spine. The range of each view extended from the external auditory meatus to the anterior superior iliac spine, providing a lateral view of the entire cervical, thoracic and lumbar spine. Obtaining an upright lateral view allowed the angle of incidence to be

Table 1. Tools for Measurement of Spinal Kyphosis

Tool	Description/Application	Advantages	Disadvantages	Reference
1. Spinal pantograph	• Used to describe and document thoracic kyphosis and lumbar lordosis of the spine • Pantograph has an arm at the end of which a low frictioned wheel is mounted. A drawing table is fixed below the pantograph for recording the contour of the spine. This apparatus is then mounted onto a tripod, which can be raised or lowered or allows the pantograph to work in the sagittal or transverse plane. • In this study, measurements from the pantograph to measure kyphotic and lordotic angles were compared with those obtained by roentgenograph. • Cobb's technique (1948) was used to determine the angle of kyphosis.	Range of thoracic kyphosis and lumbar lordosis obtained by pantograph positively correlated with that obtained by roentgenographs for patients in standing.	• Cumbersome setup • Pantograph may underestimate amount of lordosis relative to roentgenograph analysis. • Sensitivity of pantograph for repeated measurements is undetermined.	Willner (1981)[23]
2. Flexicurve (flexible) ruler	• Used to record midline contour of back • Measures spinal curvatures where angular measures are derived from the intersection of tangents to curves at various points; lengths and widths of curves can be determined from the tracing; measures regional mobility of spinal curves.			
a.	• Used to measure kyphosis and lordosis in a cross-sectional study of men and women (20–90 yr). • Variables, such as length and width of thoracic kyphosis and length and width of lumbar lordosis, were used to calculate the "index of kyphosis" (length/width).	Reproducible (reliability coefficients) for length, width, and index of kyphosis = 0.78, 0.94, and 0.78, respectively.	Validity not determined	Milne and Lauder (1974)[12]
b.	• Tested reliability of flexicurve rule in the measurement of the lumbar curve	• Strong agreement in *intrarater* reliability with Bartko intraclass correlation co-efficient value of 0.97 • Method deemed a reliable clinical measure for quantification of the shape of the lumbar spine and for intratester test-retest reliability • Measures utilized attempted to determine clinical validity (correlation coefficient = 0.87) for the measurement of lumbar curves when compared with a small number of roentgenographs	• No interrater reliability analysis of the data was performed. • Only a small number of roentgenographs were used for comparison.	Hart and Rose (1986)[9]
c.	• Determined intrarater and interrater reliability as well as the validity of the flexicurve ruler compared with roentgenographs in the lumbar spine	• Reliability: 9% test-retest reliability; 15% error in interrater reliability • Validity: correlation of 0.87 between flexicurve ruler and roentgenogram analysis		Burton (1986)
d.	• Measured lumbar spine mobility in the sagittal plane • Compared flexicurve ruler with inclinometer and roentgenographs	• Intrarater reliability r = 0.95, $P > 0.0001$ • Strong correlation between flexicurve ruler and inclinometer (r = 0.80) and roentgenographs (r = 0.93)		Tillotson and Burton (1919)
e.	• Measured cervical spine curvature in neutral and flexed positions	• Interrater reliability = 0.90; correlation between testers (r = 0.80)	• Authors commented that the flexicurve ruler may be more difficult to apply to individuals suffering from pain, disease, or postural deformities which appeared to negatively affect intertester reliability coefficients obtained in this study.	Rheault et al (1989)[15]

3. Flexicurve ruler vs. inclinometer	• Evaluated reliability and validity of flexicurve and inclinometer methods in assessment of spinal curvature	• Flexicurve ruler easier to use, convenient, lightweight; reproduces the shape of curve measured; less expensive than inclinometer • Flexicurve ruler more accurate and reproducible than inclinometer in determining angle of curvature • High correlation between measurements obtained using both methods		Thompson and Eales (1994)[21]
4. DeBrunner's kyphometer vs. inclinometer	• Used to assess spinal mobility and sagittal configuration in scoliotic patients and gymnasts with low back pain (LBP)			• Aaro and Ohlen (1983) • Ohlen et al (1989)[14]
5. DeBrunner's kyphometer	• Evaluated measurement of kyphosis, lordosis, and mobility of the spine in normal individual aged 16–61 yr • Coefficients of variation were described as low for kyphosis (8.4%), lordosis (7.4%), and for lumbar flexion (5.4%)	• Good reproducibility of kyphometer measurements for kyphosis ($0.91 < r < 0.94$) and for lordosis ($0.91 < r < 0.96$)	• Validity of kyphometer untested • Sensitivity of instrument to spinal changes over time untested	Ohlen et al (1989)
6. Kyphometer vs. goniometer vs. flexicurve vs. tape measure vs. diasonograph ultrasound echoes	• Comparison of multiple methods in the measurement of lumbar sagittal mobility	• Good correlation between use of kyphometer, goniometer, and flexicurve ruler measurements as follows: *Flexion/Extension* (i) kyphometer/goniometer ($r = 0.99/r = 0.92$) (ii) kyphometer/flexicurve ruler ($r = 0.93/r = 0.71$) (iii) goniometer/flexicurve ruler ($r = 0.94/r = 0.92$) • Due to ease of use and high reproducibility, goniometer considered the best instrument to measure spinal sagittal mobility • Validity of noninvasive instruments (i.e., kyphometer and flexicurve ruler) in the measurement of spinal deformity has been traditionally determined by comparison to roentgenograph evaluation.	• Drawing of flexicurve tracing/tangents may introduce source of error affecting its reliability • Kyphometer heavy, difficult to position accurately on spinal landmarks • Study did not involve individuals with specific spinal curvature/deformity • Note: the least correlation was between the kyphometer and flexicurve ruler	Salisbury and Porter (1987)
7. Roentgenographs	• Application of roentgenograph to derive an angle of kyphosis • Method involves drawing a line at the inferior border of the vertebra at the beginning of the kyphotic curve (typically around T4), and at the interference vertebra at the lowest part of the kyphotic curve (corresponding to the highest vertebra of the lordotic curve). The angle of incidence is measured between these two lines.		• Despite use as "gold standard," reliability and validity of roentgenographic in the measurement of spinal curvature remain undetermined.	Cobb (1948)

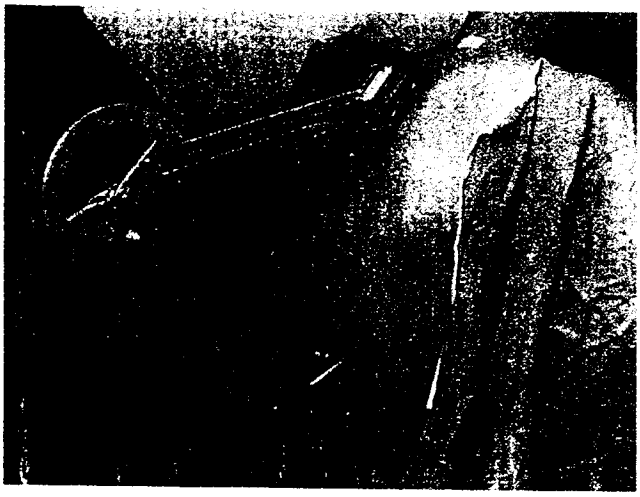

Figure 1. DeBrunner's kyphometer for noninvasive measurement of spinal kyphosis in postmenopausal women.

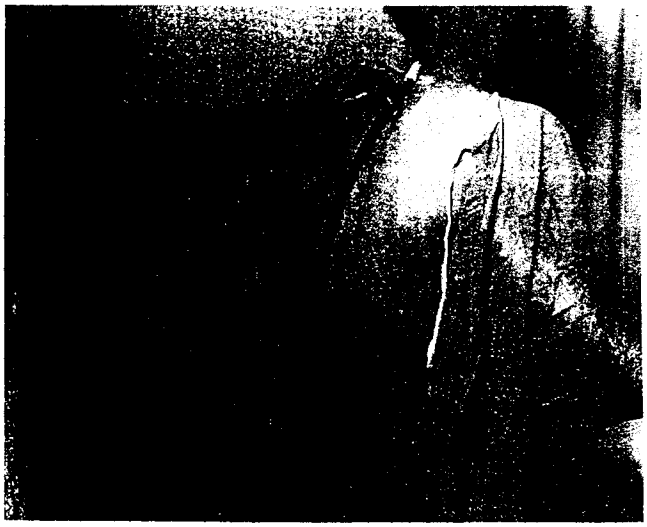

Figure 2. The flexicurve for noninvasive measurement of spinal kyphosis in postmenopausal women.

optimally measured between T4 and the interference vertebra, which is the lowest vertebra of the kyphotic curve and corresponds to the highest vertebra of the lumbar lordotic curve.[10] As with the flexicurve ruler, measurement of kyphotic curvature from the roentgenographs was made by applying the Cobb technique from which an angle of kyphosis was derived. In 12 cases, a single roentgenograph was obtained, and repeated observer analysis of spinal kyphosis was performed. In 13 cases, two roentgenographs were taken for the purpose of a single observer's analysis of each film of spinal kyphosis. Results were compared with measurements obtained using the Debrunner's kyphometer and the flexicurve ruler. Statistical and reliability analyses were conducted using a commercial software package (SAS, Toronto, Ontario, Canada).

■ Results

The data indicated highly consistent use of the DeBrunner's kyphometer and the flexicurve ruler by each observer based on the critical two-way analysis of variance (ANOVA; ICC 2,1).[18] One-way ANOVA (ICC 1,1) showed results consistent with two-way ANOVA (ICC 2,1). A summary of reliability measures is presented in Table 2. Based on the characterized values of reliability coefficients of Landis and Koch,[11] the results are empirically substantial to almost perfect (0.81–1), which permits further determination of the reliability of each instrument specifically. In general, the DeBrunner's kyphometer showed slightly higher but not significantly different intra- and interrater reliability compared with the flexicurve ruler and roentgenograph (Table 2). Repeated observer analysis of single roentgenographs indicated a higher level of reproducibility (0.98565) compared with single measurements taken from repeated roentgenographs (0.81289).

Two groups of subjects were subselected on the basis of postural deformity: normal backs (n = 11) and round backs (n = 13). Two-way ANOVA of the data from these subsets again indicates consistent use of each instrument by each observer, with some minor variations indicating observer-based instrument preference within each group (Table 3). In addition, the kyphometer had slightly superior interrater reliability measures than either the flexicurve ruler or roentgenograph in the measurement of kyphosis in the round-back sub-group.

A comparison of collapsed data, including all observers' ([n = 3] × 3) measurements in each of the 26 subjects, further indicates the strength of each instrument relative to one another (Table 4). A summary of the collapsed data for the subselected normal-back and round-back categories is presented in Table 5. Components of variance (subject, observer, interaction between subject, and observer error) were determined for the kyphometer and flexicurve ruler (Table 6).

Table 2. Summary of Reliability Measures: All Subjects (n = 26) Random Set

Model	Device	Observer			Roentgenograph (n = 25)	Roentgenograph (n = 13) (2 films, single film analysis)	Roentgenograph (n = 12) (1 film, repeat analysis)
		Observer 1	Observer 2	Observer 3			
Two-way analysis of variance [ICC (2,1)][38]	Kyphometer	0.99269	0.89059	0.99381	0.92414	0.81289	0.98565
	Flexicurve ruler	0.89142	0.93675	0.96751			

Table 3. Summary of Reliability Measures: Normal Back (n = 11) and Round Back (n = 13) Postures

Model	Postural Deformity	Device	Observer			Roentgenograph (n = 25)
			Observer 1	Observer 2	Observer 3	
Two-way analysis of variance [ICC (2,1)]	Normal back (n = 11)	Kyphometer	0.96825	0.77185	0.96792	0.94564
		Flexicurve ruler	0.65581	0.90573	0.93106	
	Round back (n = 13)	Kyphometer	0.98260	0.96425	0.99033	0.83970
		Flexicurve ruler	0.75818	0.83808	0.94836	

Finally, based on simulated data (power curve, ICC 1,1), the sample size is sufficiently large to allow conclusions based on the results of the study.[7] In addition, in the sample of 26 subjects, 42% were classified as having normal thoracic kyphosis, 50% with round-back kyphosis, and 0.08% with a flat back. This distribution of spinal postures was similar to that categorized in another study in which kyphosis was evaluated in osteoporotic subjects,[17] which infers that the present study sample was representative of this group.

■ Discussion

The two-way ANOVA (ICC 2,1) is the critical and most useful test, in that its application determines whether the test instruments are interchangeable based on their consistent application by independent observers. In this way, it was determined that there was substantially consistent use of the kyphometer, flexicurve ruler, and analysis of roentgenographs by and between each observer, making the use of these instruments observer independent. This finding alone was critical in proceeding to determine the reliability of each instrument.

Based on the data, the DeBrunner's kyphometer and flexicurve ruler may be used interchangeably. There was a negligible increase in intra- and interrater reliability with the kyphometer compared with the flexicurve ruler in whole-group analysis. However, there was a marginal increase in the reliability of the DeBrunner's kyphometer compared with the flexicurve ruler and roentgenographs in the round-back subgroup. Despite their consistent use among trained examiners, an examiner-based instrument preference existed in the whole group analysis. Evaluation of subsets of the total group based on classification of postural deformity further supported examiner-based instrument preference, indicating that clinicians may be more comfortable with the application of one tool rather than the other.

In addition, the higher variance observed in the flexicurve ruler data may be attributable to the fact that the degree of kyphosis is a derived value and inherently introduces more error. Despite the apparent and only slightly higher reliability coefficient of the roentgenograph compared with that of the flexicurve ruler and the kyphometer (3 × 3 × [n = 26]) when collapsed data are considered, it is important to recognize that this result is based on only two measurements in each of the 26 subjects and inherently would be higher value because of the diminished sampling opportunity. In fact, with repeated roentgenographic evaluation (2 × [n = 13]), a diminished reliability coefficient was observed compared with results from repeated observer analysis of single films (n = 12).

An evaluation of the components of variance for each noninvasive instrument (kyphometer and flexicurve ruler) determined that the largest source of variance was subject related, showing that the population studied was heterogeneous as is to be expected in the study of any clinical population. The least amount of variability in the use of both instruments was observer based, lending further credence to the strength of the study and having the far-reaching clinical implication that instrument use does not rely on a particular examiner. This is not to disregard the need for specific training and standardization of methods in the appli-

Table 4. Reliability Measures for All Collapsed Data: Kyphometer, Flexicurve Ruler, and Roentgenograph

Model	Device	Collapsed Data
Two-way analysis of variance [ICC (2,1)]	Kyphometer	0.88286*
	Flexicurve ruler	0.87077*
	Roentgenograph	0.92414†

* n = 26 × 3 × 3.
† n = 25 × 2.

Table 5. Reliability Measures for All Collapsed Data: Normal (n = 11) and Round Back (n = 13) Postures

Model	Postural Deformity	Device	Collapsed Data
Two-way analysis of variance [ICC (2,1)]	Normal back (n = 11)	Kyphometer (n = 11 × 3 × 3)	0.67539
		Flexicurve ruler (n = 11 × 3 × 3)	0.67087
		Roentgenograph (n = 11 × 2)	0.94564
	Round back (n = 13)	Kyphometer (n = 13 × 3 × 3)	0.79401
		Flexicurve ruler (n = 13 × 3 × 3)	0.74449
		Roentgenograph (n = 13 × 2)	0.83970

Table 6. Summary of Components of Variance of the Kyphometer and Flexicurve Ruler

Component of Variance	Kyphometer	Flexicurve Ruler
Subject	191.16389	206.06075
Observer	5.55024	2.11661
Interaction between subject and observer	16.02668	18.24038
Error	9.711368	15.98611

cation of these tools. The importance of consistent landmarking and delivery of instructions to the subject and repeating each instrument measurement at least three times must be emphasized in the application of either measurement tool to maintain test and retest reliability. These endeavors also serve to ensure the accuracy of the measurements obtained from the devices. Slight variations in posture (*e.g.*, with breathing) or resumption of habitual kyphosis may alter the degree of kyphosis obtained using any technique, including the roentgenograph.

Of great importance is that when the reliability coefficients of instruments are compared with roentgenographic results, there is no significant difference in the reliability of all three instruments. In this way, the application of a noninvasive tool such as the kyphometer and flexicurve ruler has far-reaching clinical benefits and challenges the traditional use of costly, invasive roentgenographs in determining the degree of spinal kyphosis in the osteoporotic population. Both the flexicurve ruler and kyphometer are clinically feasible in cost and ease of application. In addition, these two instruments are noninvasive and do not unduly expose the patient to any form of radiation. Finally, although the DeBrunner's kyphometer is much more costly (Can $900) than the flexicurve ruler (Can $7), both are considerably less expensive than roentgenographic evaluation. Although the kyphometer is by far the least cumbersome of all three instruments examined, the flexicurve ruler permits qualitative evaluation of postural deviation. This attribute of the flexicurve ruler permits design of a specific physical therapy management strategy for the purpose of postural retraining and for longitudinal study of kyphotic curve change induced by disease progression or therapeutic intervention. The role of early physical therapy intervention for patients with spinal osteoporosis encompasses treatment goals of improved postural alignment, maintaining or improving bone mass, increasing muscle strength and endurance, and educating the patient to use proper body mechanics. Use of of clinically feasible, noninvasive tools to measure spinal kyphosis is central to the assessment and management goals in this population. The overall conclusions in the current study are that the flexicurve ruler and DeBrunner's kyphometer are worthwhile alternatives to roentgenographic evaluation in permitting the safe, noninvasive determination of the degree of spinal kyphosis without undue exposure to roentgenographic radiation.

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