Physical therapists are interested in quantifying the impairment of lumbar spine sagittal mobility in patients with lumbar spine dysfunction. Measurements of lumbar spine mobility before and during therapeutic intervention can provide the therapist with an objective method for assessing a patient’s response to treatment. Although radiographic techniques are considered the standard for obtaining measurements of lumbar spine mobility, they are potentially hazardous to a patient if repeated measurements must be made over time (4). Hence, clinicians have chosen to quantify mobility of the spine by external measurements via such noninvasive devices as tape measures (6), inclinometers (10), and flexible curves (5, 7, 9, 13). Measurements by these instruments are less expensive and faster than radiographs, pose no associated risks to the patient, and are clinically meaningful.

Several investigators (5, 7, 9, 13) have reported use of a draftsman’s flexible curve to obtain measurements of the sagittal mobility of the lumbar spine. This technique requires that a tester manually mold the flexible curve to the midline contour of the subject’s lumbar spine. The curve is then carefully transferred to paper by tracing the outline of the flexible curve. Curvature of the lumbar spine in the sagittal plane can be calculated by two methods: one involves drawing tangent lines to the tracing of the lumbar curve at selected spinous processes (5, 9, 13), and the other uses trigonometry (7). Regardless of the method for calculating the curvature, a therapist can record the relative curvature of the subject’s lumbar spine without concern for the potentially confounding influence of hip joint motion (7).

Investigators (5, 7, 9, 13) have demonstrated the intratester reliability of measurements of lumbar spine sagittal mobility taken with the flexible curve. Furthermore, these same investigators compared measurements of lumbar spine sagittal mobility with those obtained from radiographs, and the flexible curve was judged to be a valid procedure. Tillotson and Burton (13) documented the intratester reliability and validity of the flexible curve technique by using the tangent method, whereas Hart and Rose (7) chose to use the trigonometric method. Currently, there is a lack of published information comparing the interchangeability of the two methods for calculating the degree of curvature of the lumbar spine.
in the sagittal plane with the flexible curve.

The purpose of this study was to describe in healthy subjects the intratester parallel forms (alternate forms) reliability of measurements of lumbar spine sagittal mobility obtained with a flexible curve and computed by either the tangent or the trigonometric method. If the two methods agree, then the clinician may prefer to use the tangent method for estimating the mobility of the lumbar spine because it takes less time and can provide more clinically relevant information regarding the regional sagittal plane mobility of the lumbar spine.

METHODS

The subjects were 10 volunteers (five women and five men) from Mayo Physical Therapy Education Program. The subjects' ages ranged from 23 to 37 years (\( \bar{X} \pm SD, 24.9 \pm 4.41 \) years). None of the subjects had a history of back surgery, nor did they complain of any present mechanical low back pain. None of the subjects had a scoliosis greater than 15°, as determined by visual examination. Informed oral consent was obtained from all subjects before any measurements were taken.

Testers

Measurements were made by two investigators working together, with 22 and 33 years, respectively, of teaching and clinical experience in physical therapy. For this study, the same investigator always took the measurements, and another investigator instructed the subject in the proper movement patterns. Before data collection began, the measurer practiced molding the flexible curve to the lumbar spine of 10 subjects who were not the volunteers in this study. The lumbar curve's contour was determined for each subject under three conditions: 1) relaxed upright standing, 2) maximum lumbar flexion when sitting, and 3) maximum lumbar extension when prone.

Instrumentation

The device used to obtain measurements of mobility of the lumbar spine in the sagittal plane was a draftsman's flexible curve, 61 cm long and 2 cm wide, which bends in one plane only and can maintain a fixed shape that can be transferred to paper (Acu-Arc Adjustable Curve, Hoyle Products, Inc., Fillmore, CA). Three twist-tie markers were attached to the curve to mark the position of the spinous processes of vertebrae T-12, L-4, and S-2.

Procedure

Bony landmarks of the lumbosacral spine were located with techniques described by others (5,8,13). The spinous process of the S-2 vertebra was estimated by bisecting a straight line between the lower palpable borders of the subject's posterior superior iliac spines. The spinous process of the L-4 vertebra was estimated by bisecting a straight line joining the highest palpable points of the subject's iliac crests. The spinous process of the T-12 vertebra was estimated by identifying the inferior margins of ribs T-12 bilaterally and then simultaneously palpating these rib margins while moving superiority and medially with the distal tips of each thumb until they disappeared deep into the soft tissue. At this point, the measurer estimated the location of spinous process T-12 by bisecting a straight line joining the tips of each thumb. Removable red adhesive dots, 6 mm in diameter, were placed on the skin overlying the center of each spinous process. The order of measurement was the same for each subject: the standing lumbar curve's contour was measured first, the lumbar curve's contour during maximum forward flexion when sitting was measured second, and the maximum lumbar extension when lying prone was measured third. For each posture, the subject was allowed a 1-minute rest before the measurement was repeated.

The technique for measuring the lumbar curve when the subject is standing has been described by Walker et al (14) (Figure 1). Each subject stood barefoot and assumed a comfortable erect posture with body weight evenly distributed between both feet. The instructor positioned a dowel, horizontally mounted on an adjustable stand, until it lightly touched the subject's xiphoid process. This device aided in controlling the subject's forward postural sway while the measurement was obtained. The instructor traced the outline of the subject's feet on a piece of paper attached to the base of the platform so a subsequent measurement could be taken with the subject in the same standing position. After affixing red adhesive dots to the skin overlying the spinous processes of T-12, L-4, and S-2, the measurer molded the flexible curve to the midline contour of the subject's lumbosacral spine. The sites of the flexible curve that intersected the red dots were marked by adjustable twist ties fastened to the curve. Next, the measurer carefully lifted the curve from the subject's spine and placed it on a piece of poster board without altering its configuration. While the measurer held the flexible curve, the instructor traced the convex side of the curve's outline on a piece of poster board. Additionally, marks were made along the curve's contour that corresponded to spinous processes T-12, L-4, and S-2.

Next, the subject was instructed to step off the platform, and the instructor removed the red dots from the subject. After a 1-minute rest, the subject remounted the platform and stood so that both feet were within the outlines of the previous footprint tracings. The subject's spinous processes were again palpated and marked with the adhesive dots. The previously described measurement
FIGURE 1. Procedure for measuring the sagittal mobility of the lumbar spine when the subject is standing. A) The subject stands on a wooden platform, and an adjustable dowel is mounted to a vertical rod and positioned so it lightly touches the subject's xiphoid process. The tester carefully molds the flexible curve to the midline contour of the subject's lumbar spine. Twist ties attached to the curve project horizontally and mark the location of spinous processes of T-12, L-4, and S-2. B) The contour of the lumbar spine obtained from the flexible curve is carefully traced by the tester onto a poster board. The location of spinous processes of T-12, L-4, and S-2 is marked. For the trigonometric method, line L is drawn between the spinous processes of T-12 and S-2. Next, line H is constructed so it bisects and is perpendicular to line L. The angle of the lumbar lordosis (θ) is calculated from the formula. For the tangent method, a separate tangent line is constructed to the mark along the curve representing the spinous processes of T-12, L-4, and S-2. The angle formed by the intersection of the L-4 and T-12 tangents estimated the sagittal mobility in extension of the upper lumbar spine (EUL), whereas the angle formed by the intersection of the L-4 and S-2 tangents estimated the sagittal mobility in extension of the lower lumbar spine (ELL). The sum of the two angles (EUL + ELL) estimated the contour of the lumbar spine when standing.

The technique for measuring maximum lumbar spine flexion has been described by others (5,13). The subject sat on the front edge of a chair (Figure 2) with both feet flat on the floor. The instructor asked the subject to bend forward and to try to place the head between the knees while keeping both arms lateral to the knees. Each subject performed three repetitions of trunk flexion, with a 15-second hold at the end of the range to increase compliance of the low back's soft tissues. With the subject's trunk in maximum forward flexion, the measurer palpated and marked the spinous processes according to the previously described palpation techniques. Once this was completed, the instructor told the subject to resume sitting with the trunk vertical to the chair's seat.

Next, the instructor verbally instructed the subject "to bend forward at your waist and try to place your head between your knees." At the end point of trunk flexion, the measurer molded the flexible curve to the contour of the subject's spine and marked the position of T-12, L-4, and S-2 spinous processes on the curve with twist ties. The measurer then removed the curve from the subject's back and instructed the subject to resume his or her erect sitting posture. While the measurer held the flexible curve, the instructor traced the outline of the curve on the poster board by using the concave side of the flexible curve. The adhesive dots were removed from the subject and then reapplied after a minute's rest. Without warm-ups, the procedure was repeated for a second measurement, and this tracing of the curve was placed on the reverse side of the paper from the first tracing of lumbar spine flexion.

The technique used for measuring lumbar spine extension varied somewhat from that described by previous investigators (5,13). With the subject lying prone on an unpadded table (Figure 3), the ends of a webbed belt were fastened so that the belt was located about 5 cm inferior to the subject's posterior superior iliac spines. This served to stabilize the pelvis during the backward bending maneuver. The measurer then palpated and marked the spinous
FIGURE 2. Procedure for measuring the maximum sagittal mobility of the lumbar spine when the subject is sitting.

A) The subject sits on the edge of a standard chair with feet flat on the floor and spread to shoulder width. The subject bends the trunk forward and attempts to place the head between the knees with the arms hanging vertically on the lateral side of each knee joint. The tester carefully molds the flexible curve to the midline contour of the subject's lumbar spine. Twist ties attached to the curve project vertically and mark the location of spinous processes of T-12, L-4, and S-2. B) For the trigonometric method, line L is drawn between the spinous processes of T-12, L-4, and S-2. Next, line H is constructed so it bisects and is also perpendicular to line L. The angle of the lumbar curve in flexion is calculated from the formula. For the tangent method, the tester constructed a separate tangent line to the mark along the curve representing the spinous processes of T-12, L-4, and S-2. The angle formed by the intersection of L-4 and T-12 tangents estimated the sagittal mobility in flexion of the upper lumbar spine (FUL), whereas the angle formed by the intersection of L-4 and S-2 tangents estimated the sagittal mobility in flexion of the lower lumbar spine (FLL). The sum of the two angles (FUL + FLL) estimated the contour of the lumbar spine in maximum flexion.

processes of T-12, L-4, and S-2 with red adhesive dots. Next, the instructor asked the subject to complete a prone push-up saying, “place the palms of both hands even with your shoulder joints, push down against the tabletop with your hands, and try to arch your back as far as you can by straightening your elbows. I will tell you when to stop pushing.” Then the instructor grasped the subject’s pelvis with both hands, so that the thumbs were placed over the subject’s posterior superior iliac spines, and the distal tips of the second and third fingers were positioned between the tabletop and the subject’s anterior superior iliac spines. The instructor determined the end point of the back movement when the subject’s anterior superior iliac spines began to move away from the instructor’s fingertips. This position of each extension was maintained for 15 seconds. Each subject completed three warm-ups, and the curvature of the lumbar spine was measured during movement four. After the measurer had removed the curve from the subject’s spine, the subject was instructed to resume a prone resting position with arms at the side. As before, while the measurer held the flexible curve, the instructor traced the outline on the poster board by using the convex side of the curve. The adhesive dots were removed from the subject and then reapplied by the measurer after a rest period of 60 seconds. This measurement procedure was completed a second time without the warm-ups. As before, the second tracing of prone extension was placed on the reverse side of the poster board from the first tracing.

Quantification of the curves in degrees was performed by the measurer using the tangent and the trigonometric methods. The measurer was blind to the results of one method when determining the results of the other method for each subject. The tangent method (Figures 1–3) involved drawing three different straight lines on each tracing tangent to the marks previously made at the position of spinous processes of T-12, L-4, and S-2. A clear, plastic centimeter ruler was positioned on the convex surface of the curve, so that the ruler’s 15-cm mark was located at the point indicated by a spinous process. The ruler was aligned so that the 14.5- and 15.5-cm marks were equidistant from the curve’s outline. The two angles formed by the intersection of these three tangent lines were measured by a clear plastic protractor marked in units of 1°. These angles were estimates of motion occurring in the upper (T-12 to L-4) and lower (L-4 to S-2) regions of the lumbar spine relative to the tangent line at L-4. Additionally, the sum of the two angles estimated the degree of curvature of the lumbar spine.

The second method used trigonometry (7). The points on the tracing between the spinous processes of T-12 and S-2 were connected with a straight line (L) (Figures 1–3). Next, a compass was adjusted so the distance between its arms was greater than half the length of L. The fixed arm of the compass was positioned at the point marking the spinous process of T-12, and a small arc was constructed on either side (convex and concave) of the tracing. This proce-
The procedure was also done with the fixed arm of the compass at the point marking the spinous process of S-2. The centers of the two intersecting arcs on either side of the curve were connected by a straight line \( H \), which bisected the vertical line \( L \). The lengths of \( H \) and \( L \) were used to calculate \( \theta \), the angle of the shape of the lumbar spine, from the formula reported by others (8,14):

\[
\theta = 4 \times \arctan(2H/L).
\]

Data Analysis

Descriptive Statistics

For the 10 healthy subjects, we calculated the mean difference and standard deviation of the differences between the first and second measurements of lumbar spine sagittal mobility for each of the three postures with the tangent and the trigonometric methods.

Intratester Reliability

The ICC (1,K) was used to estimate the intratester reliability for both methods. We calculated the ICC (1,1) (12) and ICC (1,2) (12) for each measurement method for the three positions by using the first and second measurements of the contour of the lumbar spine obtained with the flexible curve. The reliability of a single measurement made with the flexible curve and calculated by either the tangent or the trigonometric method was estimated by ICC (1,1) for each of the three positions of the lumbar spine. Additionally, the reliability of the average of the two measurements from each method was estimated by ICC (1,2) for each of the three positions of the lumbar spine.

Parallel (Alternate) Forms Reliability

Parallel forms intratester reliability for measurements of the lumbar curvature obtained with the flexible curve was expressed by a graphic technique (1–3) that visually assesses the differences between the two methods (Figures 4–6). For each of the 10 subjects, we plotted the algebraic difference between the value of their first measurement obtained by each method (tangent-trigonometric) against the mean value of their first measurements for each of the three postures of the lumbar spine. Because the true value is not known, the mean of the two measurements is

![Figure 3](image1.png)

**FIGURE 3.** Procedure for measuring the maximum sagittal mobility of the lumbar spine in prone lumbar extension. A) The subject lies prone on an unpadded table and a belt is fastened so that it passes underneath the table and above the subject's buttock to stabilize the pelvis during the backward bending maneuver. The subject then places the palms of the hands at shoulder width, pushes against the table, and passively extends the lumbar spine. The tester carefully molds the flexible curve to the midline contour of the subject's lumbar spine. Twist ties attached to the curve project vertically from and mark the location of the spinous processes of T-12, L-4, and S-2. B) The contour of the lumbar spine obtained from the flexible curve is carefully traced onto a poster board. The location of spinous processes of T-12, L-4, and S-2 is marked. For the trigonometric method, line L is drawn between the spinous processes of T-12 and S-2. Next, line H is constructed so it bisects and is perpendicular to line L. The angle of the lumbar curve (\( \theta \)) in extension is calculated from the formula. For the tangent method, the tester constructed a separate tangent line to the mark along the curve representing the spinous processes of T-12, L-4, and S-2. The angle formed by the intersection of L-4 and T-12 tangents estimated the sagittal mobility in extension of the upper lumbar spine (EUL), whereas the angle formed by the intersection of L-4 and S-2 tangents estimated the sagittal mobility in extension of the lower lumbar spine (ELL). The sum of the two angles (EUL + ELL) estimated the contour of the lumbar spine in passive maximum lumbar extension when prone.

![Figure 4](image2.png)

**FIGURE 4.** Difference (degrees) between tangent and trigonometric methods of measuring lumbar spine lordosis by a flexible curve when the subject is standing, as a function of the mean value of each pair of readings (N = 10).

![Figure 5](image3.png)

**FIGURE 5.** Difference (degrees) between tangent and trigonometric methods of measuring maximum lumbar spine flexion by a flexible curve when the subject is sitting, as a function of the mean value of each pair of readings (N = 10).
Intratester Reliability—Trigonometric Technique

The ICC (1,1) (12) was 0.87 for standing lumbar lordosis, 0.84 for maximum lumbar flexion when sitting, and 0.97 for maximum lumbar extension when prone. The ICC (1,2) (12) was 0.93 for standing lumbar lordosis, 0.91 for maximum lumbar flexion when sitting, and 0.98 for maximum lumbar extension when prone.

Parallel (Alternate) Forms Intratester Reliability

Figures 4–6 display the plots of the algebraic differences (y-axis) vs. the mean value (x-axis) for each of the three positions of the lumbar spine, as measured by the two methods. For standing lumbar lordosis, lumbar curvature estimated by the tangent method ranged from 7° above to 5° below the value obtained by the trigonometric method. For maximum lumbar flexion, the value obtained by the tangent method ranged from 3° above to 4° below the value obtained by the trigonometric method. For lumbar extension, the value of the lumbar curvature estimated by the tangent method ranged from 4° above to 4° below the value obtained by the trigonometric method.

DISCUSSION

Intratester Reliability

For the tangent method, ICC (1,1) (12) demonstrated good intratester reliability for measurements of standing lumbar lordosis and high reliability for lumbar flexion and lumbar extension. The ICC (1,2) (12) demonstrated high reliability for standing lumbar lordosis, sitting lumbar flexion, and prone lumbar extension. For the trigonometric method, ICC (1,1) (12) demonstrated good intratester reliability for lumbar lordosis. This finding agrees with results reported by Hart and Rose (7) and Walker et al (14). For measurements of lumbar flexion, we found good reliability, whereas for lumbar extension, we found high reliability. When ICC (1,2) (12) was used, we found high intratester reliability for standing lumbar lordosis, lumbar flexion, and lumbar extension. The reliability of the average of two measurements made by either method estimated by ICC (1,2) would be expected to be larger than the reliability of a single measurement [ICC (1,1)]. However, the difference between the ICC values (Table 2) suggests that the reliability of a single measurement of lumbar spine sagittal mobility would not be improved enough to warrant spending the extra time with the patient to make a second measurement.

Parallel (Alternate) Forms Reliability

We found clinically acceptable interchangeability of measurements made by the tangent and the trigonometric techniques (Figures 4–6) because the between-methods differences were ± 5° of each other. For each of the three different postures of the lumbar spine, algebraic differences between the methods plotted against their mean value did not show any systematic tendencies across

The reliability of a single measurement of lumbar spine sagittal mobility would not be improved enough to warrant spending the extra time with the patient to make a second measurement.
the range of measurements. For example, as the mean value of lumbar spine sagittal mobility increases (Figures 4–6), the difference in degrees between the two methods does not also appear to increase systematically over the range of the measurements. Therefore, when obtaining estimates of the curvature of the lumbar spine in the sagittal plane by using a flexible curve, we believe the tangent and trigonometric methods can be used interchangeably because differences in the measurements on the order of 4° to 7° should not affect the clinical decisions made on the basis of the measurements (1–3).

On the basis of these data, we believe the flexible curve is a reliable method for obtaining an estimate of the sagittal mobility of the lumbar spine when a single tester makes repeated measurements. From a clinical perspective, the flexible curve has an advantage over other noninvasive methods because it can provide the physical therapist with a permanent visual record of the midline contour of the patient's lumbar spine when the patient is standing or sitting or in prone extension. This visual record may be educational in that the patient can observe how different postures alter the shape of the lumbar spine. Measurements of the contour of the patient's lumbar spine taken by the flexible curve can assist the physical therapist in objective assessment of changes in the mobility of the lumbar spine in response to selected treatment strategies.

Furthermore, although the tangent and trigonometric methods are interchangeable for measuring the contour of the lumbar spine with the flexible curve, we believe that the clinician would prefer the tangent method because it permits the tester to measure regional sagittal mobility in the lower lumbar spine (L-4 to S-2) and upper lumbar spine (L-4 to T-12) and to calculate total sagittal plane mobility within the lumbosacral spine (S-2 to T-12) (5). For example, during relaxed upright standing (Figure 1), the angle of curvature of the lumbar lordosis was estimated to be 33° by the trigonometric method. However, by the tangent technique, extension of the lower lumbar spine (EUL) was calculated to be 18°, whereas extension of the upper lumbar spine (EUL) was 15°. The sum of EUL and ELL provided a contour of 33° of lumbar lordosis. For both standing lumbar lordosis and lumbar flexion (Figures 1 and 2), sagittal mobility of the upper and lower lumbar spine was about equal, whereas for lumbar extension when prone (Figure 3), there was more sagittal mobility in the upper lumbar spine (27°) compared with the lower lumbar spine (16°). Although flexible curves and inclinometers use the same geometric principles for estimating total lumbar spine sagittal mobility, only the flexible curve allows the clinician to obtain measurements of a subject's sagittal mobility for the lower and the upper portions of the lumbar spine.
RESEARCH STUDY

Furthermore, we preferred the tangent to the trigonometric method because it required less equipment and it took less time. Using the tangent method, we calculated the angle of curvature of a lumbar curve in about 45 seconds. This included drawing three tangent lines and measuring two angles. On average, it took about 2 minutes to calculate the angle of curvature by the trigonometric method.

One practical limitation associated with the flexible curve technique for measuring lumbar spine mobility is the need for two therapists.

One practical limitation associated with the flexible curve technique for measuring lumbar spine mobility is the need for two therapists. It was our experience that the flexible curve had some elasticity, causing it to recoil if both ends were not held securely against the poster board. Therefore, the measurer held the flexible curve, whereas the instructor traced its contour. Additional study is needed to investigate the reliability of measurements of lumbar spine sagittal mobility obtained with the flexible curve in obese patients. Excessive soft tissue would make it difficult to manually palpate and mark the spinous processes of vertebrae T-12, L-4, and S-2. Moreover, the excessive soft tissue could interfere with proper molding of the flexible curve to the midline contour of the subject’s lumbar spine.

CONCLUSION

We conclude that measurements of sagittal mobility of the lumbar spine obtained with the flexible curve from healthy subjects in standardized postures demonstrate high intratester reliability when computed by either the tangent or the trigonometric method. Additionally, we found high parallel (alternate) forms intratester reliability when the tangent and the trigonometric methods were used to calculate the contour of the lumbar spine obtained by the flexible curve when the subject was standing, in maximum lumbar flexion, and in prone extension. Furthermore, we believe the tangent method is preferable to the trigonometric method for calculating sagittal mobility of the lumbar spine because it is less time-consuming and provides the clinician with objective information about the regional sagittal mobility of the upper and lower portions of the lumbar spine in addition to mobility of the whole lumbar spine.

REFERENCES