Research Report

Intrasubject Reliability of Spinal Range of Motion and Velocity Determined by Video Motion Analysis

Background and Purpose. The purpose of this study was to investigate the repeatability of spinal range of motion (ROM) and movement velocity measurements of patients with chronic low back pain, using a two-dimensional motion analysis system. This apparatus uses reflective markers placed on anatomical landmarks and video digitization to derive ROM measurements from three segments of the spine and associated velocities through the respective ROMs. Subjects. Forty-two patients with chronic LBP underwent ROM and movement velocity testing. Methods. Each subject was tested twice without removal of the markers to minimize error contribution from differences in marker placement. Results. Results indicated that both the ROM measures and the velocity measures were highly repeatable. Intraclass correlations for the ROM measures ranged from .77 to .96. Velocity measures were also reliable, with intraclass correlation coefficients ranging from .75 to .97. Conclusion and Discussion. Overall, the results seem to indicate that the video motion analysis system used in this study yields repeatable ROM and velocity measures on a clinical population. In practice, however, the measures may reflect greater errors due to the need of examiners to relocate markers at different testing sessions. These systems also offer distinct advantages over other means of obtaining ROM and velocity measures. The results of this study indicate that these measures may be obtained without undue concern for measurement artifact due to the instrumentation reliability. [Robinson ME, O'Connor PD, Shirley FR, Mac Millan M. Intrasubject reliability of spinal range of motion and velocity determined by video motion analysis. Phys Ther. 1993;73:626-631.]

Key Words: Backache; Movement science; Spine; Tests and measurements, range of motion.

Low back pain (LBP) is a widespread problem affecting 80% of the population and resulting in an estimated 32 million visits to physicians per year. Many different treatment and measurement devices have been used to quantify loss of function and disability from low back injuries. One measure of spine function is range of motion (ROM). The American Medical Association's guide for percentage of permanent impairment uses loss of ROM of the lumbar spine as one component of disability. Radiographs have long been the "gold standard" in measuring ROM of the spine. Subjecting the patient to multiple series of radiographs to document progress, however, is expensive and time consum-
ing and exposes the individual to unnecessary radiation.

Other methods of measuring lumbar spine ROM include the use of inclinometers, measurement of fingertip-to-floor distance, lumbar extension rehabilitation devices, and video analysis of markers placed on anatomical landmarks. Loeb,\(^1\) using an inclinometer, found more than half of the spinal flexion and extension below the neck occurred in the lumbar spine. One fifth to one fourth of the lumbar ROM occurred into extension, and the remainder was flexion ROM. Mayer et al\(^3\) used a two-inclinometer method and reported measurements within 10% of those found using a radiographic method. There were no significant differences in measurements made using a double-inclinometer method versus radiography.

Gauvin et al\(^6\) used a modified fingertip-to-floor method to measure forward bending in a group of patients with LBP and found that this method yielded reliable measurements. They did not investigate the relationship between fingertip-to-floor and lumbar flexion measures. Other data\(^7\) suggest that a strong linear relationship between lumbar flexion and the distance of fingertips to floor may not exist.

Marras and Wongsam\(^8\) used an electronic device worn by the patient to measure flexion-extension of the lumbar spine as well as movement velocity. They found patients with LBP had a 25% reduction in trunk ROM. The patients’ movement velocities were also significantly reduced 50% for flexion and 90% for extension compared with those of control subjects. These results seem to indicate that movement velocity and ROM may be important factors in LBP.

Another method of measuring ROM involves placing skin markers on anatomical landmarks and then measuring the distances between these markers with the subject in different postures. This method has been used in a group of patients with ankylosing spondylitis,\(^9\) for comparison of persons with LBP and asymptomatic individuals,\(^10\) and to investigate normal ROM and decreases with age and sex differences in flexion and lateral side bending.\(^11\)

Few studies have examined full ROM and movement velocities of the spine. Gracovetsky et al\(^12\) reported differences in ROM between measurements determined with external markers and those obtained with a radiographic method. Their data indicate that the differences were possibly attributable to dynamic movement versus static postures used by the different systems of measurement.

Gomez et al\(^13\) and Parnianpour et al\(^14\) have reported ROMs and movement velocities of the lumbar spine in a restraining device and found both sets of measurements to be reliable. These devices, however, may not represent naturally occurring situations and may restrict the generalizability of the results because of the artificial movement imposed by restraining the patient to isolate lumbar musculature.

Those methods of ROM measurement that isolate motion between the sacrum and L-1 have been found to be the most reliable when compared with radiographic methods.\(^3,5\) Flexible rules have been shown to give repeatable measurements, but may produce inaccurate measurements in obese patients because of skinfolds.\(^4\) Rehabilitation devices that attempt to isolate lumbar musculature may also restrict the generalizability of the obtained ROM measurements to naturalistic settings.

With the advancement of technology, the use of computer analysis of human motion has become less laborious.\(^15,16\) Prior to the advent of these motion analysis systems, cinematography of human motion was hand-digitized frame by frame and then analyzed by a motion-analyzing device.\(^17\) These devices offer the advantage of allowing the therapist to obtain both ROM and velocity measurements in a minimally restrictive setting.

Today there are automated and semi-automated programs available for analyzing human motion. Initially, these programs were used for gait analysis, though there are now programs to analyze spinal motion, foot motion, lifting, and sport activities. Few studies have been published that have investigated the repeatability of computer-analyzed human motion. Those studies that have been published have primarily focused on gait variables and the repeatability of angle measurements.

Kadaba et al\(^18\) reported that measurements of gait variables are quite repeatable with subjects walking at their natural speed. They reported some variance across days due to variability in alignment of markers. Thurston and Harris\(^19\) reported repeatable and identifiable patterns of spinal and pelvic movements during gait. Peacey et al\(^20\) reported repeatable movement of the lumbar spine and similar patterns measured radiographically for maximal movements in all planes of motion. Whittle\(^15\) reported rapid and reliable kinematic data from a three-dimensional system. Winter et al\(^21\) reported normal ROM and velocities of joint motion of the extremities in gait at varying speeds.

The purpose of this study was to investigate the repeatability of spinal ROM and movement velocity measurements in patients with chronic LBP, using a two-dimensional video motion analysis system (Motion Analysis SPINETRAX\(^{TM}\)). An advantage of this device is that it does not restrict the patients' movement, allowing for a more naturalistic determination of function.
Method

Subjects

All data were taken from subjects (33 men, 9 women) who were being evaluated by a multidisciplinary team for a back rehabilitation program. Each subject was assessed using the Motion Analysis SPINETRAK® system as part of his or her physical therapy evaluation. All subjects had pain for greater than 6 months. The mean age of the sample was 38.5 years. All subjects were receiving workers' compensation benefits. All subjects signed an informed consent statement authorizing their clinical data to be used for research purposes.

Instrumentation

The Motion Analysis SPINETRAK® system is a two-dimensional motion tracking and analysis system. It is an automated system that tracks retroreflective markers. Depending on the motion (flexion/extension, lateral side bending, or rotation), 4, 8, or 10 retroreflective spheres or disks are tracked. One video camera with an 8-mm lens was used to record the images. Data were archived on videotape and analyzed at a later date. Videotaped marker data were processed at 15 frames per second using a Motion Analysis VP310® and then analyzed on a microcomputer. The software program is automated; thus, once marker identification is confirmed, the program automatically analyzes and computes ROMs and movement velocities.

Procedure

Because the SPINETRAK® system measures in two dimensions, ROM must be determined separately for each plane of motion. For flexion/extension, 2.5-cm passive reflective disks were placed at the sternum; at T-1, T-12, and S-2; at the left greater trochanter; and 5 to 10 cm below the greater trochanter bilaterally. The subject stood with his or her back toward the camera so the subject's image occupied the largest possible area of the video monitor. Neutral position was standing erect, facing straight ahead, with back toward the camera, arms in front of body with hands clasped, and feet shoulder width apart.

Rotation was done in a sitting position. The camera was fixed overhead approximately 150 to 240 cm above the subject, dependent on the subject's height. Passive reflective spheres, 2.5 cm in diameter, were placed at the acromial process bilaterally, and a 15-cm stick with two passive reflective disks 5 cm apart was placed at S-2. Neutral position was seated with erect posture and facing straight ahead, with feet flat on the floor, knees straight ahead, and arms across the chest.

Order of data collection was always as follows: lateral bending, flexion/extension, and rotation. All data collection was part of a physical therapy evaluation for involvement in a multidisciplinary back rehabilitation program. Each subject was required to perform two sets of five repetitions in each plane of motion. There was a 10- to 15-second pause between each set and a 2- to 3-minute pause between motions. Subjects were instructed to move only in the plane of motion being analyzed. Compensatory movements were shown and discouraged. Subjects did three or four repetitions to ensure markers remained within camera range, to check for compensatory movements, and to give the patient a warm-up practice. The subjects were instructed to comfortably move as far as they could, as fast as they could, for the full set of repetitions without stopping. These instructions were identical for each motion analyzed. The command for the start of each data-acquisition trial was "Ready, begin." Following the first set of five repetitions, the subject paused in the neutral position for 10 to 15 seconds and another set of five repetitions began. Following the second set, markers were switched and the subject was positioned for the next series of measurements.

Data Analysis

Data were processed using the SPINETRAK® software program. The average ROM and movement velocity values were calculated for each set of five repetitions. The average ROM value was determined by using the total ROM divided by the number of repetitions. The average movement velocity measure was determined by dividing the total degrees per second by the number of repetitions. Flexion-extension measurements of spinal motion were obtained for lumbar, thoracolumbar, and thoracolumbopelvic regions. Similar measurements were obtained for lateral side bending in the lumbar and thoracolumbar regions. Rotation measurements were obtained for only the thoracolumbar region.

The five repetitions each for flexion, extension, left and right rotation, and left and right lateral bending were averaged using software provided with the apparatus (Tab. 1). These means were used in subsequent data analyses.

Results

Intraclass correlation coefficients were calculated for each of the 12 ROM and movement velocity measures. The correlations for the ROM measures ranged from .77 to .96. For the velocity measures, the correlations ranged...
Table 1. Descriptive Statistics and Test-Retest Comparisons of Measurements of Spinal Range of Motion (ROM) and Movement Velocity

<table>
<thead>
<tr>
<th>Site</th>
<th>ROM (°)</th>
<th>Velocity (°/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test 1</td>
<td>Test 2</td>
</tr>
<tr>
<td></td>
<td>X</td>
<td>SD</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>26.2</td>
<td>11.3</td>
</tr>
<tr>
<td>Extension</td>
<td>10.4</td>
<td>8.0</td>
</tr>
<tr>
<td>Left lateral bending</td>
<td>14.3</td>
<td>5.4</td>
</tr>
<tr>
<td>Right lateral bending</td>
<td>14.5</td>
<td>6.5</td>
</tr>
<tr>
<td>Thoracolumbar spine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>25.1</td>
<td>9.5</td>
</tr>
<tr>
<td>Extension</td>
<td>13.6</td>
<td>9.8</td>
</tr>
<tr>
<td>Left lateral bending</td>
<td>24.5</td>
<td>7.7</td>
</tr>
<tr>
<td>Right lateral bending</td>
<td>25.3</td>
<td>6.9</td>
</tr>
<tr>
<td>Left rotation</td>
<td>37.5</td>
<td>10.2</td>
</tr>
<tr>
<td>Right rotation</td>
<td>36.9</td>
<td>11.1</td>
</tr>
<tr>
<td>Thoracopelvic spine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>57.3</td>
<td>17.9</td>
</tr>
<tr>
<td>Extension</td>
<td>18.8</td>
<td>9.4</td>
</tr>
</tbody>
</table>

from .75 to .97. All correlations were significant at $P<.001$. The correlational analyses indicate that the apparatus yields good reliability for both ROM and velocity measurements. Intraclass correlations for all variables are presented in Table 2.

These results, taken as a whole, indicated good consistency of both ROM and movement velocity measurements using the SPINETRAK® device with persons who had chronic LBP. In addition, the obtained measurements appeared stable and did not show a practice or fatigue effect with only two testing sessions.

Discussion

The measurement of spinal motion with video motion analysis, especially in an unrestricted task, offers distinct advantages over other methods of assessment. Little evidence, however, has been presented in the literature on the reliability of measurements obtained with such devices in patient populations.

Reliable measurement with motion analysis devices is imperative before clinical decisions can be made. The results of our study show that good consistency can be obtained for both ROM and velocity measurements. All test-retest correlations were statistically significant, though there were differences in reliability for different measures.

The correlations for ROM were lowest in the lumbar flexion measurement, whereas velocity correlations were lowest in lumbar extension. This increased variability could be due to the subjects' fear of a forward flexed posture and pain with extension. Larger motion segments showed slightly higher correlations, indicating the possibility of subtle motion and velocity changes to compensate for smaller segment changes.

There are many potential sources of error when motion analysis systems are used. These errors include application of markers by several investigators, removal and reapplication of markers, and skin movement over bony landmarks. This study examined repeatability of ROM and velocity measurements with a clinical protocol in a clinical population. Because markers were not removed between data sets, error due to reaplication of markers was eliminated. One investigator applied all markers to all subjects, thereby minimizing variability due to marker placement. The consistency of ROM and velocity measures may have been enhanced as a result of these controls, and applications involving consistency across days (involving reaplication of markers) or across investigators may yield less reliable information. The variability in ROM and velocity measurements in this study was therefore limited to intrasubject variability, instrumentation error, and the afore-
mentioned movement of markers relative to bony landmarks. The relative contribution of these sources of variability is beyond the scope of this study, but warrants further study. This project serves as an initial starting point for further study and suggests that the apparatus itself yields repeatable data in a clinical population.

One study22 has shown that the use of a motion analysis system results in reliable measurements of static postural angles. It has been assumed that such systems are accurate and reliable for motion analysis, though no direct comparison has been made. Our study shows that the SPINETRACK® motion analysis system has good intrasubject reliability for measuring ROM and movement velocity in patients with chronic LBP.

Although we feel that the reliability of data produced by this motion analysis system has been established with this study, it remains to be seen how the obtained measurements correspond to measurements obtained with more traditional clinical methods of ROM assessment. The clinical implications of ROM assessment are great. Loss of motion is used to set impairment ratings, which has a direct financial impact on the patient and third-party provider. No studies have examined the relationship of static versus dynamic ROM measurements. It could be postulated that dynamic ROM and velocity measurements may be more indicative of impairment than static measurements because dynamic measurements are more naturalistic. Before this can be established, however, normative data and their correlation to functional activities must be established.

Future research with these systems must examine the correspondence of dynamic ROM and movement velocity measurements with more traditional measurements obtained in the clinic (eg, liquid inclinometry measurements) before conclusions regarding accuracy can be made. The relationship of functional ability to motion analysis measurements must also be assessed before the utility of these systems can be determined. Instrumentation sources of error must also be studied, including marker placement errors and multi-

### Conclusions

Motion analysis systems allow for quantitative measurements of human motion in a more realistic setting compared with systems that isolate certain musculature or otherwise constrain the subject. The results of this study suggest that SPINETRACK® ROM and movement velocity measurements are reliable for patients with chronic LBP. This study was seen as a fundamental first step in establishing the intrasubject reliability and validity of this system for clinical use. The clinical implications are that these systems may be able to help quantify anatomical limitations and their relationship to functional limitations, though more research is needed in this area. Further study is needed of the effects of marker replacement, day-to-day repeatability, and errors due to marker misplacement.

### References

22 Vander Linden DW, Carlson SJ, Hubbard RL. Reproducibility and accuracy of angle measurements obtained under static conditions with the Motion Analysis® video system. Phys Ther. 1992;72:300-305.

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