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Normal motion of the lumbar spine as related to age and gender

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Summary. The CA-6000 Spine Motion Analyzer was used to measure the lumbar spine's range of motion (ROM). One hundred and four asymptomatic volunteers were examined to obtain normal values for flexion/extension, lateral bending, and axial rotation. A detailed error analysis was conducted to investigate the inter- and intraobserver reliability of the measurement equipment, the differences between passive and active examination, the effects of stretching exercises before examination, and the diurnal changes related to lumbar spine ROM. Subjects were divided into groups by age and gender. Values for each group were compared with respect to age and gender. The measurements were found to be consistent and repeatable. Stretching exercises were observed to increase ROM. Passive examination was recommended to achieve maximum ROM. ROM was observed to increase during the course of the day. A normative database was established showing significantly decreased motion as age increased, but no gender differences were discovered. The validity of the axial rotation values due to fixation difficulties is questioned.

Key words: Lumbar spine – Range of motion – Diurnal changes

The assessment of lumbar spine range of motion (ROM) is important clinically, for both patients suffering from low-back pain and pain-free subjects. Current measurement techniques include inclinometers, goniometers, and computer-assisted measurement systems, such as the Isostation B-200 Lumbar Dynamometer (Isotechnologies, Carboro, N. C.). All exhibit varying degrees of reliability and accuracy. However, normative data for lumbar spine ROM is unsatisfactorily documented in the literature. The challenge remains to develop a noninvasive, in vivo method to evaluate lumbar spine ROM. The method should minimize errors, yet remain simple enough for use in a clinical setting. Once a reliable examination technique and protocol have been established, normative data for lumbar ROM can be collected.

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Aims of the study

- To measure the difference between actively and passively performed motion of the lumbar spine
- To measure the inter- and intraobserver reliability of the measurement technique
- To investigate the effects of stretching exercises before examination
- To investigate diurnal changes in lumbar ROM
- To establish normative age and gender related motion (ROM) of the lumbar spine

Methods

Study population

One hundred and four (62 male, 42 female) volunteers who reported no back pain within the past year were examined. Ages ranged from 20–70 years, with a mean of 40 years of age. All were informed about the procedure by one of the examiners before the examination and agreed to participate in the study.

Measurement equipment

The study used the CA-6000 Spine Motion Analyzer (Orthopaedic Systems, Hayward, Calif.) to measure three-dimensional motion. The CA-6000 consists of six high precision potentiometers in a linkage consisting of seven metal bars. The linkage system allows unrestricted three-dimensional motion. There are three potentiometers to measure flexion/extension, two potentiometers to measure lateral bending, and one potentiometer to measure axial rotation. A change in angle of the linkage system (due to movement) corresponds to a change in resistance of the potentiometers, which is recorded in real time by a personal computer. The software program simultaneously collects and records both main and coupled motions as degrees versus time (Fig. 1).

Examination technique

The examination is performed by attaching the linkage to the subject at the sacrum and the thoracolumbar junction. A standard fixation procedure has been developed. The sacral mounting plate is

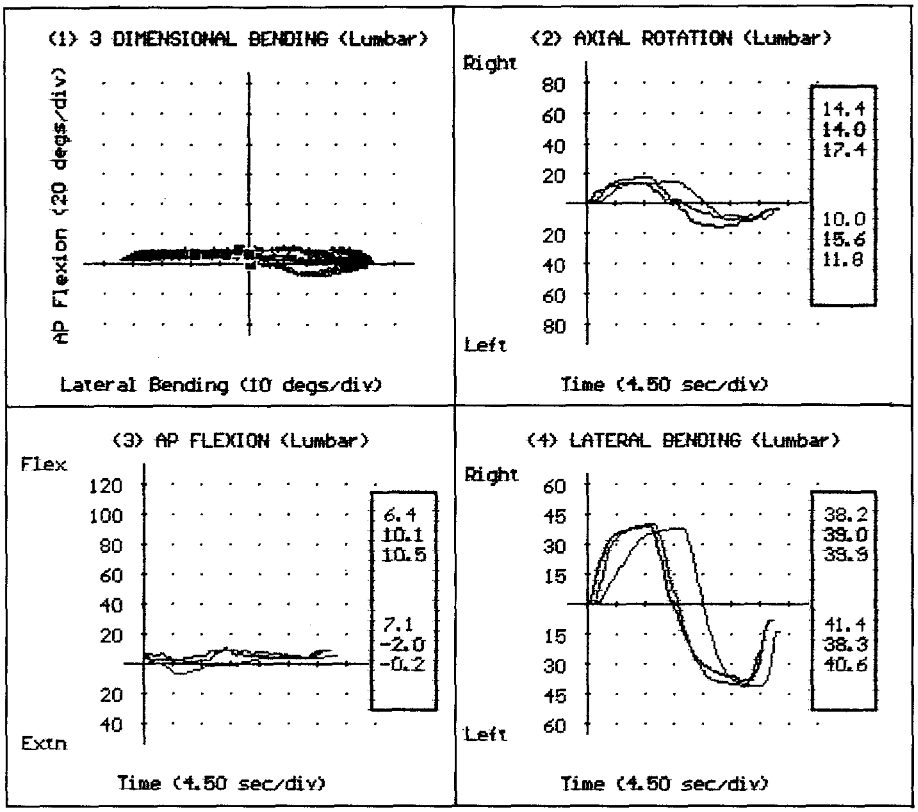


Fig. 1. Computer printout of a lateral bending examination. Degrees versus time are plotted for all three dimensions, and a combined diagram is included. Notice that the computer displays flexion during a lateral bending examination, which provides a means of verifying that the subject remained in a neutral plane

attached to the body by a set of two rubber straps which are tightened around the subject's waist. The straps are placed anteriorly over the hip bones to limit slipping, and the mounting plate is placed posteriorly on the sacrum. The thoracic mounting plate is attached by a strap around the subject's chest at the level of the thoracolumbar junction, which is found by palpation (Fig. 2). The initial mounting system provided by the company had difficulties measuring extension in extremely mobile subjects. The upper and lower segments of the linkage should not come into contact as this effectively blocks any further extension readings. This can be corrected by simply lengthening the sacral mounting bar by 10 cm, thus eliminating any contact between the upper and lower segments of the linkage. The sacral mounting plate is assumed to be a fixed reference position; therefore, lengthening of the mounting bar and placement of the linkage upon the bar do not affect the results.

Before the examination was conducted, the subject was instructed to stretch the muscles of the lower back. The exercise routine consisted of five repetitions of flexion/extension, lateral bending, and axial rotation. The linkage was then attached, and the subject was instructed to stand in a normal, neutral position while the device was electronically zeroed. The range of motion for the following three passively performed tests were collected: (1) flexion/extension (Figs. 3,4), (2) lateral bending (Fig. 5), (3) axial rotation (Fig. 6). For the lateral bending test, the subjects were instructed to stand with their toes touching the wall. This was to block any forward flexion during the lateral bending test. Each test consisted of three trials, and the maximum of the three trials was the reported value. The entire examination took approximately 15 min to complete for each subject.

Statistical analysis

All statistical analyses were performed on an Apple Macintosh personal computer using SYSTAT (1800 Sherman Avenue, Evanston, Illinois) statistical software. A multivariate analysis of variance, paired *t*-test, coefficient of variation, or linear regression was used where appropriate.

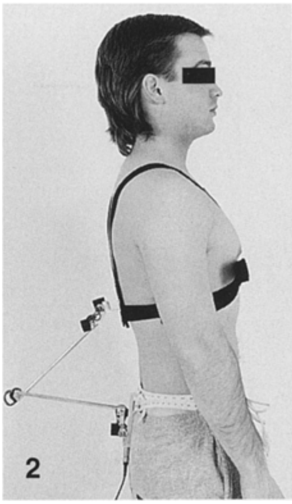
Results

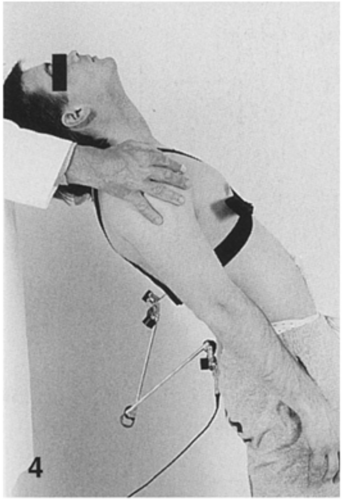
Active/passive comparison

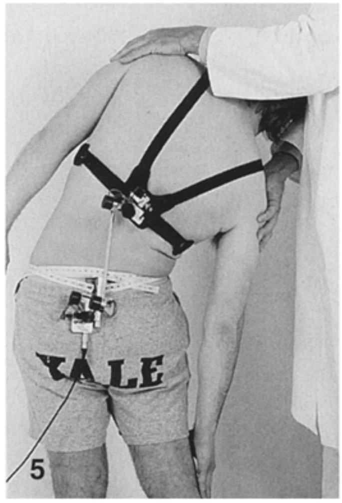
Eighteen volunteers (age 21–56 years, mean 38) were consecutively tested both passively and actively by the same examiner. Nine were tested first passively and then actively. The other nine were tested in the reverse order, so as to eliminate effects from learned behavior or preconditioning. Passive examinations resulted in a greater range of motion for flexion/extension and for axial rotation. The difference was statistically significant ($P < 0.05$, paired t-test) for axial rotation. Lateral bending, however, showed significantly ($P < 0.05$) more mobility during the active examination (Table 1). It was observed that several subjects flexed forward during the lateral bending test, contrary to instructions to remain in a neutral plane. During the passive examination, the examiner restricted forward flexion, which may account for the greater mobility in the active examination. Based upon the greater range of motion for flexion/extension and axial rotation and the ability to eliminate complex coupled motions, passive examination was used for the remainder of the study.

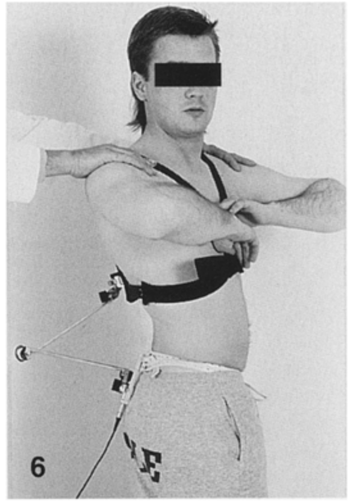
Intraobserver reliability

Fourteen volunteers (age 21–49 years, mean 35) were passively tested at the same time of day on 3 consecutive days by the same examiner. To account for the range of motion variaton for these volunteers, the coefficient of variation was calculated. This unitless parameter relates the standard deviation to the mean as a ratio. In the biological sciences, a value of 5 or 6 is assumed to be average, with the majority of all values falling in the range from 4 to 10 [11].









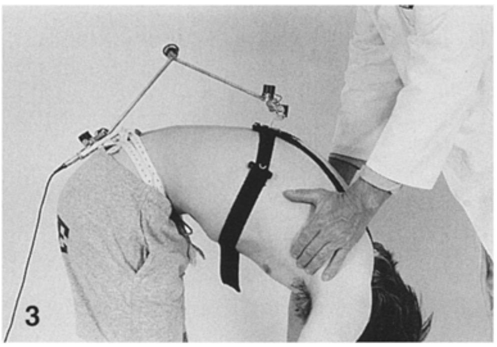


Fig. 2. Photograph of volunteer just prior to testing. Linkage has been properly attached to the sacrum and the thoracolumbar junction

Fig. 3. Passively performed flexion examination. The examiner applies a force to the shoulders to induce the maximum possible range of flexion

Fig. 4. Passively performed extension examination. The examiner applies a force to the shoulders to induce the maximum possible range of extension

Fig. 5. Passively performed lateral bending examination. The volunteer stands facing the wall, and the examiner applies a force to the shoulders to induce the maximum possible range of lateral bending. The examiner must be careful to limit forward flexion during the examination. The examination is performed to the left and right sides

Fig. 6. Passively performed axial rotation examination. The examiner applies a force to the shoulders to induce the maximum possible range of rotation. The examination is performed to the left and right sides

Table 1. Chart showing mean values and standard deviations in a comparison of active versus passive examination

Motion	Active	Passive
Flexion/extension	89.5° (17.7°)	91.6° (18.5°)
Lateral bending*	70.4° (15.3°)	67.7° (13.1°)
Axial rotation*	65.0° (15.3°)	74.8° (16.5°)

* Significant difference ($P < 0.05$)

The coefficient of variation for all three motions was within this range, with the average value of 5.8 indicating good repeatability over a 3-day period (Table 2).

Interobserver reliability

Twenty volunteers (age 31–58 years, mean 39) were consecutively tested by the same two examiners. After the first ten subjects, it was observed that the lateral bending reliability was very poor. It was believed that forward flexion during lateral bending resulted in inconsistent data. The next ten subjects were tested while standing with their toes touching the wall. The wall served to block forward flexion movements. Only the ten subjects tested in this manner were included in the lateral bending comparison. The examinations were passively conducted, and the examiners were blind to each other's results. A linear regression was used to compare the two examinations. The average r^2 value of 0.78 and average difference of 2.2% demonstrate very good interobserver reliability (Table 3).

Table 2. Results from an intraobserver comparison. Flexion/extension and lateral bending show good repeatability over a 3-day period. Axial rotation data were not as repeatable

Motion	Average coefficient of variation
Flexion/extension	5.4
Lateral bending	5.3
Axial rotation	6.7
Total	5.8

Table 3. Data from an interobserver comparison. Correlation coefficients and mean percentage difference between the two examinations demonstrate good interobserver reproducibility

	R^2 Value	% Difference
Flexion/extension	0.851	2.5%
Lateral bending	0.72	3.0%
Rotation	0.771	1.2%
Average	0.78	2.2%

Effects of stretching

Ten volunteers (age 31–50 years, mean 37) were passively examined by the same examiner before and after a short stretching routine. Lateral bending and axial rotation showed an increase in mobility following the stretching exercises. Flexion/extension showed a small decrease.

Table 4. Effects of stretching exercises on range of motion (mean and SD). Lateral bending and axial rotation show an increase in flexibility after stretching exercises

Motion	Before exercise	After exercise
Flexion/extension	86.9° (10.5°)	85.4° (9.8°)
Lateral bending*	63.8° (9.2°)	68.1° (8.8°)
Axial rotation	87.3° (7.5°)	89.8° (8.9°)

* Significant difference ($P < 0.05$)

Table 5. Chart showing the diurnal variations in range of motion. Significant increases were observed, predominantly in the first half of the day

	Flexion/ extension	Lateral bending	Axial rotation
Morning	84.5°	67.5°	76.8°
Midday	90.8°*	70.8°	85.7°*
Evening	91.0°*	70.3°	84.3°*

* Significant increase from morning ($P < 0.05$)

Only the lateral bending examination showed a significant difference (P <0.05, paired t-test; Table 4). Although these results were not conclusive, the data indicate that stretching exercises may increase ROM, and all subjects were tested following a stretching program for the remainder of the study.

Diurnal changes

Nineteen volunteers (age 21–46 years, mean 33) were passively examined by the same examiner three times during the course of one day. All subjects were tested in the morning (8:00–10:00), at midday (12:00–14:00), and in the evening (17:00–19:00). For all three motions, there was a large increase from morning to midday and very little increase or decrease from midday to evening. Statistically significant increases ($P < 0.05$, single factor, repeated measure ANOVA) were observed for flexion/extension and axial rotation (Table 5). Based upon these results, all tests were performed in the afternoon or evening for the remainder of the study.

Age and gender grouped normal values

One hundred and four volunteers (age 20–70 years, mean 40) were passively examined in the afternoon or evening following a stretching program. The volunteers were grouped by gender and the following age decades: 20–29, 30–39, 40–49, and over 50 years of age (Table 6). There were only minor gender differences, with male subjects having slightly greater mobility. Subjects were observed to have left/right symmetry in axial rotation and lateral bending. The range of motion tended to decrease with increasing age. Statistically significant differences ($P < 0.05$, MANOVA) across age decades were observed, but not across gender.

Discussion

Measurement error

The errors involved in this type of examination are relatively straightforward. Errors are introduced by the device itself, the fixation of the device on the subject, and errors caused by the examiner.

The equipment has been reported by the company to be accurate and reliable. Our independent results obtained in an earlier study confirm the accuracy of the device [5]. The device error is negligible when compared with other error sources.

The fixation of the device on the subject is the most obvious source of error. Intraobserver studies demonstrated good repeatability over a 3-day period, especially for flexion/extension and lateral bending movements, which would indicate that fixation was consistent, although it may not have measured the "true" spinal ROM.

Table 6. Normal values grouped by age and gender (mean and SD). Motion showed significant decreases with increasing age. No significant gender differences were observed

Motion	Gender	20–29	30–39	40–49	50+
Flexion	Male	75.4° (13.1°)*	63.8° (6.2°)	61.6° (11.1°)	59.5° (6.2°)
	Female	67.9° (6.8°)	62.6° (10.5°)	55.0° (12.8°)	56.2° (5.8°)
Extension	Male	31.9° (8.4°)	24.2° (8.7°)	23.0° (12.7°)	20.1° (7.3°)
	Female	28.5° (10.5°)	24.7° (14.4°)	17.5° (7.5°)	20.4° (8.6°)
Lat. bending left	Male	34.8° (6.4°)	33.0° (6.7°)	31.5° (8.2°)*	23.9° (7.9°)
	Female	32.0° (5.8°)	33.5° (8.8°)	28.4° (7.8°)*	20.1° (8.1°)
Lat. bending right	Male	36.2° (5.3°)	36.1° (7.2°)*	31.2° (8.0°)*	24.5° (7.8°)
	Female	31.4° (8.4°)	34.8° (8.1°)	29.0° (6.5°)	23.5° (7.9°)
Axial rot. left	Male	47.6° (11.2°)	47.0° (9.9°)	41.9° (9.4°)*	33.8° (7.6°)
	Female	40.5° (10.4°)	45.5° (11.5°)	38.6° (8.8°)	33.7° (8.3°)
Axial rot. right	Male	47.9° (11.2°)	46.8° (7.7°)*	40.8° (10.5°)*	32.3° (7.1°)
	Female	46.1° (12.5°)	44.8° (11.5°)	38.2° (7.5°)	35.8° (7.0°)

* Significant difference from age decade to adjacent right

Table 7. Comparison of mean values obtained with the CA-6000 to previous radiographic studies. Flexion/extension and lateral bending are similar; axial rotation values do not agree

	Flex/ext	Lat. bending	Ax. rotation
X-ray	88.9°[a]	57.7°[a]	21.6°[b]
CA-6000	86.6°	64.0°	86.3°

[a] Data from [4]
[b] In vitro data from [13]

It has been observed that the mounting plates do slip across the skin, and the soft tissue slides across the spine, especially during axial rotation movements. The measurements may have included the soft-tissue movement rather than measuring vertebral range of motion. This is a problem inherent in most noninvasive examinations of the spine. To help investigate the validity of the measurements (i.e. how accurately the device measures the "true" spinal ROM), we compared our results to those found in an earlier study of lumbar spine ROM using functional X-ray analysis [4]. Subjects 60 years and older were eliminated from the comparison so as to achieve a comparison of similar age groups. Mean age was 37.2 years for CA-6000 subjects and 37.7 for X-ray subjects. The range of motion for the X-ray analysis was defined to be the sum of rotations from the sacrum to T12. Similar values were measured in flexion/extension and lateral bending with both procedures (Table 7). No in vivo data exist for an accurate comparison of rotary movement. To make some estimate of the validity of our rotational data, we compared our results to in vitro data. Yamamoto et al. used functional CT scans to obtain in vitro measurements [13]. They observed an average axial rotation of 10.8° to each side, measuring from the sacrum to L1. Although these values do not include the rotation of T12 and they are not in vivo, the data are significantly different from our findings (Table 7). While we have not developed a technique to eliminate the fixation problem completely, these results indicate that the CA-6000 can accurately measure spinal ROM in flexion/extension and lateral bending movements. We question the validity of the axial rotation values due to the fixation difficulties.

The results from interobserver studies are encouraging. A relatively high correlation between examiners indicates that the examiner errors are minor, provided the examiner has been properly instructed in the testing procedure.

Active vs passive examination

Based upon our direct comparison of the two examinations, it has been established that passive examination results in a greater range of motion for flexion/extension and axial rotation. Lateral bending, however, showed a greater range of motion in the active examination. An examination of the coupled motions indicates that this was the result of forward flexion during the actively performed lateral bending examination. Forward flexion introduces complex motion patterns that are not the focus of this study. If the goal is to achieve the range of possible motion for the three described movements, passive examination is strongly recommended. We do not question the value of active examinations if coupled motions are of interest, as this was not the subject of this study.

Effects of stretching exercises

A comparison of lumbar spine ROM before and after stretching exercises indicates that stretching increases the range of motion. Lateral bending showed a significant increase. A small decrease was observed in flexion/extension, yet this is believed to be within the errors of measurement. It cannot be conclusively stated that stretching exercises increase the mobility of the lumbar spine, but there is no indication that stretching decreases mobility. For this reason, we advocate a short stretching program prior to examination.

Diurnal variations

It has been observed in the literature that lumbar spine ROM increases during the course of the day [12]. Our findings are in agreement with previous studies. The majority of this augmentation occurs in the morning, with little or no variation during the afternoon and evening. Increases were large enough to be considered statistically significant. We, therefore, do not believe that the maximum ROM can be measured in the morning. To achieve maximum ROM, testing must be performed during the afternoon or evening.

Age and gender normal values

It was not possible to make a direct comparison of lumbar spine ROM with that from other studies because other studies do not offer age- and sex-related normal values based upon a passive examination. The American Medical Association and Gerhardt and Rippstein have measured normal values without regard to age and gender [1, 6]. Other studies are simply comparisons of various measurement techniques and their reliabilities [2, 3, 8–10]. Gomez et al. used a computer-assisted method to actively examine a sufficiently large population; however, the computer method has been noted in recent studies to have poor reproducibility [3, 7].

Our findings indicate that ROM values decreased with age for all three motions. Statistically significant differences were observed between age decades. The largest decrease for lateral bending and axial rotation occurs after the fourth decade. The largest decrease occurs much earlier, after the second decade, for flexion/extension. There was no significant gender difference within age groups. Male subjects were, however, observed to have greater mobility in virtually every age decade. Gender differences have been excluded in the final results (Tables 8, 9; Fig. 7). Symmetrical right versus left motion was observed in axial rotation and lateral bending.

The CA-6000 has been demonstrated to be a reliable ROM measurement system. A reliable three-dimensional motion measurement system could be used in the future to evaluate: impairment assessment, motion patterns related to disease, pre- and postoperative comparisons, three-dimensional coupled motion patterns, and clinical documentation.

Conclusion

The CA-6000 Spine Motion Analyzer is a reliable, reproducible method to measure in vivo motion of the lumbar

Table 8. Normal values (mean and SD) grouped by age. Left/right symmetry can be observed

Motion	Age (years)			
	20–29	30–39	40–49	50+
Flexion	71.4° (10.7°)*	63.4° (7.8°)	59.2° (11.9°)	58.0° (6.1°)
Extension	30.2° (9.2°)	24.4° (11.0°)	21.2° (11.2°)	20.2° (7.7°)
Lat. bending left	33.2° (6.1°)	33.2° (7.4°)	30.3° (8.0°)*	22.2° (8.0°)
Lat. bending right	33.5° (7.4°)	35.6° (7.4°)*	30.4° (7.4°)*	24.1° (7.6°)
Axial rot. left	43.6° (11.0°)	46.5° (10.3°)*	40.7° (9.1°)*	33.8° (7.7°)
Axial rot. right	46.9° (9.9°)	46.1° (9.1°)*	39.3° (9.4°)*	33.9° (7.1°)

* Significant difference from age decade to adjacent right

Table 9. Normal values (mean and SD) grouped by age. Significant age differences can be observed

Motion	Age (years)			
	20–29	30–39	40–49	50+
Flexion/extension	102.4° (10.4°)*	87.1° (10.4°)*	79.1° (15.6°)	78.5° (10.3°)
Lateral bending	66.8° (11.1°)	68.8° (14.2°)*	60.7° (14.7°)*	46.3° (15.1°)
Axial rotation	90.5° (19.5°)	92.6° (17.9°)*	80.6° (17.4°)*	67.7° (12.8°)

* Significant difference from age decade to adjacent right

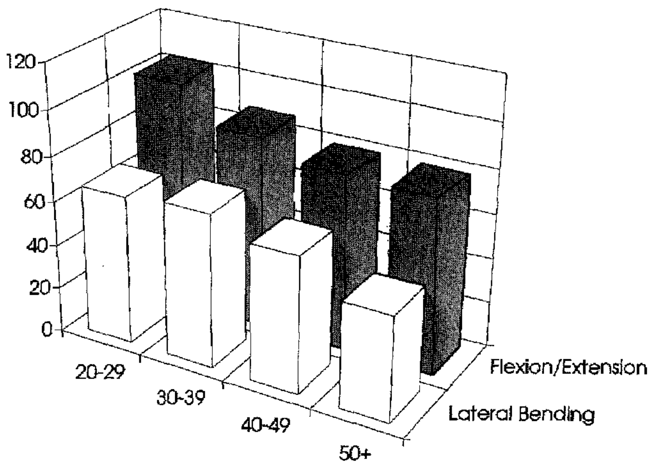


Fig. 7. Graph indicating an overall decrease in motion with increasing age. Average values for each age decade are plotted for all three motions. Notice the large decrease in flexion/extension after the second decade. The largest decrease for lateral bending occurs after the fourth decade. Axial rotation values are not believed to be accurate

spine in a clinical setting. Flexion/extension and lateral bending movements can be effectively measured. Axial rotation is less useful for clinical examination, due to technical difficulties.

There is a significant increase in lumbar spine ROM during the course of the day. The majority of this increase occurs during the first half of the day. Any measurement of lumbar ROM must be performed after midday to obtain accurate values.

Normative data relating age and gender to lumbar spine ROM was established. There were significant variations between age decades, which suggests that other methods of comparison currently in use are invalid and subject to error. Any examination of lumbar spine ROM must take into account age differences.

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