

Measurement of Normal Lumbar Spine Range of Motion in the College-Aged Turkish Population Using a 3D Ultrasound-Based Motion Analysis System

Üniversite Çağındaki Türk Popülasyonunda Normal Lumbal Omurga Hareket Kapasitesinin Ultrason Tabanlı Üç Boyutlu Hareket Analiz Sistemi Kullanılarak Ölçümü

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Objectives: The aim of this study was to determine range of motion values of lumbar spine in Turkish people by using 3D motion analysis method.

Patients and Methods: The study included 100 subjects (50 males, 50 females; range 18 to 22 years). The Zebris® 3D Motion Analysis System was used for the measurement. Lateral bending, flexion, extension, pelvic tilt were evaluated in the measurements.

Results: The average value for total lateral flexion at lumbar spine was found to be $51.3^{\circ} \pm 7.5$ in males and $52.7^{\circ} \pm 9.9$ in females. Total flexion-extension was $81.0^{\circ} \pm 11.1$ in males and $80.2^{\circ} \pm 10.2$ in females. L4-L5 flexion, L5-S1 extension values were statistically high in women ($p < 0.05$) while L3-L4 total flexion-extension and L1-L2 total lateral flexion values were statistically high in men ($p < 0.05$). The support of pelvic tilt to total lumbosacral flexion was 46.6% in males and 42.1% in females. The support was 36.8% in males and 26.2% in females during extension. Flexion and extension of pelvic tilt values in men were found to be significantly higher than that in women ($p < 0.05$).

Conclusion: The normal values of movements of lumbar spine in Turkish people have been determined with 3D motion analysis system.

Key words: Range of motion; pelvic tilt; lumbar spine; Turkey.

Amaç: Bu çalışmanın amacı Türk toplumunda üç boyutlu hareket analiz metodunu kullanarak lumbal omurga hareket kapasitesi değerlerini tespit etmektir.

Hastalar ve Yöntemler: Ölçümlere 100 gönüllü denek (50 erkek, 50 kadın; dağılım 18-22) alındı. Hareket ölçümleri için "Zebris® 3D Motion Analysis System" kullanıldı. Ölçümlerde lateral fleksiyon, fleksiyon, ekstansiyon, pelvik tilt hareketleri değerlendirildi.

Bulgular: Lumbal bölge total lateral fleksiyon erkeklerde $51.3^{\circ} \pm 7.5$, kadınlarda $52.7^{\circ} \pm 9.9$ olarak bulundu. Total fleksiyon ekstansiyon hareketi erkeklerde $81.0^{\circ} \pm 11.1$, kadınlarda $80.2^{\circ} \pm 10.2$ idi. L4-L5 fleksiyon, L5-S1 ekstansiyon değerleri istatistiksel olarak kadınlar için daha yüksek iken ($p < 0.05$), L3-L4 total fleksiyon-ekstansiyon ve L1-L2 total lateral fleksiyon değerleri istatistiksel olarak erkeklerde daha yüksekti. Pelvik tiltin total lumbosakral fleksiyon hareketine katkısı erkeklerde %46.6, kadınlarda %42.1 idi. Ekstansiyon hareketi esnasında katkısı erkeklerde %36.8, kadınlarda %26.2 olarak bulundu. Pelvik tilt fleksiyon ve ekstansiyon değerleri erkeklerde kadınlara göre anlamlı olarak daha yüksek bulundu ($p < 0.05$).

Sonuç: Türk toplumunda lumbal omurganın hareketlerinin normal değerleri üç boyutlu hareket analiz sistemi ile tespit edilmiştir.

Anahtar sözcükler: Hareket kapasitesi; pelvik salınım; lumbal omurga; Türkiye.

It is essential to know the normal range of motion (ROM) values for proper diagnosis of spine problems. It is also helpful during the course of treatment as one may observe the progression of an illness and the patient's recovery. Other studies suggest that joint motion changes depending on factors such as medical condition,^[1-9] age, sex,^[1,2,5] pelvic asymmetry,^[6] race,^[5] geographical distribution,^[5] somatotype, daily activity level and exercise.^[1,2,5] Therefore, every society should identify their ROM values. Various methods and devices are used for motion analysis. Schober technique, radiologic researches, videofluoroscopic analysis, goniometry and inclinometry are the most frequently used,^[4,9-16] however, nowadays the devices which enable three dimensional motion analysis on the skin have been developed due to technological advance. These are the devices such as Moire topography, photogrammetry, video raster stereometry, optoelectronic scanner (Qualysis, Vicon), ultrasound scanner (Zebris® CMS 70P, CA 6000 Spine Motion Analysis, Germany) and cineradiography.^[3,8-14,17-26]

The aim of this study is to determine and standardize ROM values of lumbar spine motions of Turkish people by using three dimensional motion analysis method.

PATIENTS AND METHODS

One hundred subjects at the age of 18-22 took part in the measurements. There were 50 males (average age: 19.2 ± 1.0 years, height: 175.5 ± 5.3 cm, weight: 66.8 ± 8.3 kg) and 50 females (average age: 19.4 ± 1.0 years, height: 164.4 ± 5.7 cm, weight: 53.9 ± 6.2 kg). After being informed about the aim and method, those who were volunteers participated in the study. It was taken into consideration that the subjects had no physical and orthopaedic problems, no structural disorders of the spine, no history of trauma, operation and rheumatic disorders as well as no existence of neurologic deficiencies.

Measurement of lumbar spine motion was performed using 3D motion analysis system (Zebris® CMS 70P, CA 6000 Spine Motion Analysis, Germany).^[3,27-29] This system senses and records the angular changes occurring in

motion of joint by using high frequency sound waves. The system offers some advantages such as precise measurement on the skin, computerized data evaluation. It records 0.1 degree ROM loss during the measurements. The device consists of separate components. It has surface markers sending intermittent high frequency ultrasonic sound waves that are placed on the skin. Other components of the system are the receiver microphones sensing the sound waves produced by the markers which are placed in the angles and the unit that integrates the markers, sensors, adapters and computer in order to convert the sound waves into data.

The motions of lumbar spine such as lateral bending, flexion, extension and pelvic tilt were evaluated in the measurements. The measurements were carried out at the same hours of the day. The room temperature was kept in normal conditions. The markers were placed and the measurements were made by the same researcher. The device was adjusted to collect 10 Hz frequency for each marker. Measurements for the male and female subjects were made separately. The motions were performed at least five times, consequent ROM degrees performed by active movements were recorded three times for each subject. As the starting position, the subjects were kept in the erect position with their back facing the sensors. The sensors were placed 60 cm away from the subject in order to make a 70° angle between the sensor and vertical axis of the ground (Fig. 1).

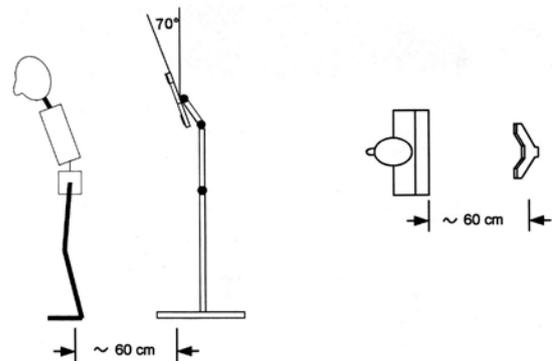


Fig. 1. Starting position.

The length of the sensor was adjusted for the subject. The first and second markers were placed on posterior superior iliac spine. The third marker was placed between S2 and S3 spinous processes. The other markers were placed on the intervertebral spaces between L1 and S1. Lateral bending first to the right and then to the left permanently without bending the knees were performed by the subjects after calibration, to enable only spine and pelvis to carry out motions by preventing hip flexion. After the measurement of lateral bending was finished, calibration was performed again in erect position, following this, the subjects were asked to carry out flexion and extension motions permanently without bending their knees and moving neck region. During that period, the motions were observed and recorded.

Winspine analysis program (Zebris®, Germany) was used for lumbar spine motion. In order to measure the motion of a vertebra, three of the markers which we placed on skin are necessary. When the middle one of the three markers placed on spinous processes changes its position according to the other two, the value of angular difference is calculated.

This is the angle between the line drawn from the marker below to the middle marker and line drawn from the marker above to the middle marker (Fig. 2). Consequently, the marker, angle of which has been measured, records the motion of vertebra on which it is placed.

After recording all the measurements, the reports of them were obtained. The measure-

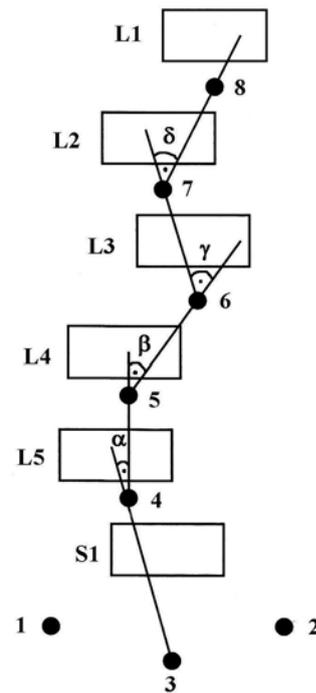


Fig. 2. Positioning of the markers and their angulations.

ments of all the subjects were transferred to the computer program. Comparison of the variables between males and females was tested using Student's t test. A p value of <0.05 was considered statistically significant. The Statistica 7.0 (StatSoft Inc. Tulsa, OK, USA) statistical package was used for statistical analysis.

RESULTS

Mean values and standard deviations of flexion, extension and lateral flexion are shown in Tables 1 and 2.

Table 1. Lumbar spine lateral flexion results (°)

Segments	Male (n=50)			Female (n=50)		
	RLF	LLF	TLF	RLF	LLF	TLF
L1-L2	3.4± 1.7	2.9± 1.7	6.3± 2.4	4.5± 2.4	4.2± 2.4	8.7± 3.9
L2-L3	5.0± 2.6	5.7± 1.8	10.7± 3.0	6.2± 2.9	5.9± 2.9	12.1± 4.4
L3-L4	6.0± 3.2	5.4± 3.1	11.4± 4.6	4.7± 3.3	5.7± 3.3	10.5± 4.9
L4-L5	4.7± 2.1	4.5± 2.6	9.2± 3.3	4.5± 2.9	3.8± 2.2	8.4± 3.4
L5-S1	7.5± 2.5	6.1± 2.2	13.6± 3.3	6.6± 3.6	6.4± 3.9	13.0± 6.3
Total	26.6± 4.9	24.7± 3.4	51.3± 7.5	26.6± 5.5	26.0± 5.4	52.7± 9.9

RLF: Right lateral flexion; LLF: Left lateral flexion; TLF: Total lateral flexion.

Table 2. Lumbar spine flexion-extension results (°)

Segments	Male (n=50)			Female (n=50)		
	F	E	T	F	E	T
L1-L2	7.7±2.1	1.8±1.4	9.6±2.7	7.2±3.3	2.4±2.1	9.7±4.0
L2-L3	12.1±3.7	3.7±4.1	15.7±5.5	11.1±3.8	2.8±3.9	13.9±4.8
L3-L4	15.3±4.9	4.6±4.9	19.9±6.9	13.6±5.6	3.1±3.2	16.7±6.2
L4-L5	13.2±5.4	6.4±5.4	19.5±7.4	15.6±5.3	4.7±4.4	20.2±6.1
L5-S1	13.3±4.2	3.0±5.0	16.3±7.7	14.4±6.2	5.3±4.0	19.7±8.2
Total	61.6±8.1	19.4±8.3	81.0±11.1	61.8±7.8	18.4±6.2	80.2±10.2

F: Flexion; E: Extension; T: Total flexion-extension.

L4-L5 flexion, L5-S1 extension and L5-S1 total flexion-extension values in women were statistically higher than that in men ($p<0.05$). L3-L4 total flexion-extension and L1-L2 total lateral flexion values were statistically high in men ($p<0.05$). No difference was found for the other variables.

Mean values and standard deviations for pelvic tilt are shown in Table 3. Considering these data, as for healthy individuals, the contribution of pelvic tilt to the total lumbosacral flexion is 46.6% in males and 42.1% in females. These values are 36.8% and 26% respectively, during extension. It is observed that females use their lumbar spine while males use their pelvic and hip joints. Flexion and extension of pelvic tilt in men were found to be significantly higher than that in women ($p<0.05$).

DISCUSSION

We compared our data with the data of the researches carried out on the topic in the literature. There are differences between our studies and the studies carried out utilizing radiographic techniques. Of the researches in which segmental lateral bending measurements were

carried out, in the studies of Pearcy et al.,^[9] Pearcy and Tibrewal,^[10] differences between L4-L5 and L5-S1 segments were encountered. In these studies, it was mentioned that as the age increased, movement capacity decreased. In the study of Dvorak et al.,^[11] a difference between L5 and S1 segments was observed, while other segments were in accordance with their values. It was reported in the literature that as the age and body weight increase, ROM decreases.^[1,8,12]

When we reviewed the studies of Pearcy et al.,^[9] Putto and Tallroth studies,^[21] we observed that our values in other segments were higher than the segmental flexion-extension measurements except L1-L2 segment. The methodology and age group are different in our study from these studies. Besides, the subjects Putto and Tallroth^[21] used in their studies were unhealthy. The data Hayes et al.^[18] and Dvorak et al.^[11] obtained from healthy subjects using the same method are in accordance with our results. Wong et al.^[16] used the videofluoroscopic method in their study. They measured the total lumbar flexion as 40° and the extension as 10° and obtained lower values than ours in all the segments they studied. The average age of the par-

Table 3. Pelvic tilt results (°)

	Male (n=50)			Female (n=50)		
	PT	LSF	T	PT	LSF	T
Flexion	53.6±12.0	61.6±8.1	115.1±13.7	45.0±12.6	61.8±7.8	106.8±16.3
Extension	11.3±7.4	19.4±8.3	30.8±10.9	6.5±4.2	18.4±6.2	24.9±7.5

PT: Pelvic tilt; LSF: Lumbar spine flexion; T: Total lumbosacral flexion.

ticipants in their study is lower than ours. They used different measurement points. The angle between the imaginary lines passing through the inferior and the superior margins of the vertebral bodies were measured in this study. It was shown that ROM decreases in people who have low back pain.^[9,10,14,20,27] Utilization of the radiographic techniques is common in measuring the lumbar region segment movements. The reliability of this technique is high, but due to the difficulties in its utilization and its high cost, this technique is more applicable in patients. Due to harmful effects of x-rays, the movements cannot be repeated adequately. The quality of graphs influences the examination process.^[16,24] The graphs taken inappropriately cause misevaluation.^[4,12,14] Thanks to the method and instrument we use, the actions may be done continuously. Repetitive measurements can be done without imposing any risk on the subject. The pelvic tilt is performed in our method and especially during the L4-S1 segment movement, the contribution of pelvic tilt occurs. Our instrument cannot differentiate this feature of the pelvis for lateral bending movement. The effect of pelvic tilt is eliminated in radiological researches.

The methods and age groups are different in goniometric and inclinometric studies. Total lateral flexion values Fitzgerald et al.^[12] and Dillard et al.^[13] obtained by using goniometry are higher than our results. Fitzgerald et al. found this value by measuring the distance between C7 and pelvis. Thoracic region is excluded from measurements in our results. Fitzgerald mentioned that as the age increased, a decrease in ROM values occurred. Dillard et al. placed the probe of the instrument between Th12 and L1. Joseph et al.^[14] found that total lateral flexion value was 61 ± 11 as it was 53.3° for Mellin et al.^[4] Both of them used inclinometric methods in their studies. The values Joseph et al. obtained are 10° higher than ours. As well as methodological difference, placement of the inclinometer is also different. The instrument was placed between T12 and L1 spinous processes in the study, so one segment more was measured. The results of Mellin et al. are in accordance with our results. Goniometry and inclinometry do not allow segmental mea-

surements to be carried out. Dillard et al. found that total flexion-extension ROM value was 91 ± 14 in their studies. Flexion values are in accordance with ours, but our extension values are about 9° lower than their values. As we mentioned earlier, the measurement of the distance between Th12-S2 segment was carried out in the study by using goniometric method. Our age group is younger. Alaranta et al.^[19] determined that total-flexion-extension value was 63° in their research. Joseph et al.,^[14] Ensink et al.,^[11] determined that total flexion-extension ROM values in their studies were 71° and 54.3 , respectively. The common feature of these three studies is that they all used inclinometric method. The values they obtained are lower than ours. As a difference, the group Ensink et al. studied were the patients with backache. The age groups in these three studies were again higher than ours. There are studies which inform that the difference of the measured points and posture disorder affect the results of measurement.^[4,8,14,17]

There are also studies which utilize three dimensional movement analysis techniques methodologically. Robinson et al.^[22] utilized the video motion analysis method to find out lumbar region ROM values and the reliability of the instrument. In this study they found that lateral flexion movement was 28.8 for lumbar region. This value is significantly lower than our value. The subjects were unhealthy and they had been suffering from backache for more than six months. In addition, the age group was 20 years older than ours.

With OSI CA 6000 spine motion analyzer -which is a different instrument from the one we used in our study- Petersen et al.^[20] and Coates et al.^[8] determined that the total lateral flexion ROM values were 87° and 54° , flexion-extension ROM values were 93° and 110° , respectively. These values are higher than ours. The instrument carrying out three dimensional measurement consists of two markers, one of which is placed on the back and the other on the hips and a computer. By this method, the movements between thoracolumbar junction and sacrum may be measured. Although Petersen et al. mentioned that the values were for lumbar region,

they actually measured the region between Th7-S2. For this reason, their values are higher than ours. Coates et al. evaluated the Th12-S2 distance and gave its results. This is also different from our measurements. Both the technique and the instrument used in the measurements, and the segmental differences in placing the markers may explain the difference between the values.

During our research we also encountered a study carried out by using Zebris® 3D motion analysis system instrument which we used in our study. It was noted that this system is a method which gives reliable results for both neck and lumbar region measurements of the spine.^[27-29] The aim of Schreiber's^[27] research is to identify the relationship between chronic backache and ROM values and to investigate the effect of backache on segmental movements. In the study, 16 of the subjects didn't have backache within the last two years, 36 of them were males and had backache for more than three months. However, it was taken into consideration that the patients did not have severe backache during the measurement. The mean age of the healthy group which we compared with our subjects is 40.3 ± 7.8 . Eight markers were used in this study. Segmental flexion-extension values are lower than the values we obtained in our study. The use of an older age group may have a role in the difference between the results.

Using the instrument called "3 SPACE ISOTRACK" which was developed for another three dimensional movement analysis method, Russell et al.^[23] determined that lumbar region total flexion-extension ROM value was 91° in females, 100° in males. These values are higher than the ones we got. In another research, using 3 SPACE FASTRACK instrument, Lee et al.^[30] showed that lumbar region flexion-extension value was 75° . This value is in accordance with our results. The level between L1 and S1 was measured in both studies. Fatallah et al.^[2] who used LMM measured the movement of lumbar spine in certain hours of the day and checked whether they were different or not. He found the value as 86° between the hours 10:00 and 12:00 which is the period of the day we performed our measurements. Having different results in spite

of using the same methods or having similar results in spite of using different methods makes us consider that ROM values may be influenced by different geographical conditions, anthropological characteristics, period of the day and daily activities as well as method and age difference.^[1,2,5,8]

The ROM values of spine movements have been measured with three dimensional movement analysis method. There are differences between the values we obtained and the ones in the literature. We think that these differences are due to the methodological differences, the utilization of different instruments, the difference of the points used for the measurements especially in three dimensional movement analysis methods, difference between subjects' age groups, anthropological, geographical and daily activity differences of the societies measured. The normal values of lumbar lateral flexion, flexion and extension movements of the spine in Turkish people have been determined. Utilization of the Zebris® 3D Motion Analysis System enabled the measurements to be carried out on the skin. This is a practical, precise instrument which has no harm for people. We think that this instrument can be used successfully in clinic areas. We believe that normal values we determined will be more useful for following prognosis before and after the treatment and deciding how the treatment will be planned, which we consider more important, rather than the diagnosis of the spine pathologies. We feel that the values we obtained will be useful not only in medical area but also in ergonomics and sports sciences. Further studies should be planned in the future to measure the values of the age groups outside ours, patient groups and those in sports activities; and to evaluate the relations between them.

REFERENCES

1. Ensink FB, Saur PM, Frese K, Seeger D, Hildebrandt J. Lumbar range of motion: influence of time of day and individual factors on measurements. *Spine* 1996;21:1339-43.
2. Fathallah FA, Marras WS, Wright PL. Diurnal variation in trunk kinematics during a typical work shift. *J Spinal Disord* 1995;8:20-5.
3. Cigali BS, Ulucam E, Yilmaz A, Cakiroglu M. Comparison of asymmetries in ground reaction force

- patterns between normal human gait and football players. *Biol Sport* 2004;21:241-8.
4. Mellin G, Kiiski R, Weckström A. Effects of subject position on measurements of flexion, extension, and lateral flexion of the spine. *Spine* 1991;16:1108-10.
 5. White AA, Panjabi MM, editors. *Clinical biomechanics of the spine*. 2nd ed. Philadelphia: Lippincott; 1990.
 6. Humphreys SC, Hodges SD, Lumpkin KJ, Eck JC, Wurster R, Hagen J, et al. Assessing lumbar sagittal motion using videography in an in vivo pilot study. *Int J Ind Ergon* 2007;37:653-6.
 7. Al-Eisa E, Egan D, Deluzio K, Wassersug R. Effects of pelvic asymmetry and low back pain on trunk kinematics during sitting: a comparison with standing. *Spine* 2006;31:E135-43.
 8. Coates JE, McGregor AH, Beith ID, Hughes SP. The influence of initial resting posture on range of motion of the lumbar spine. *Man Ther* 2001;6:139-44.
 9. Pearcy M, Portek I, Shepherd J. The effect of low-back pain on lumbar spinal movements measured by three-dimensional X-ray analysis. *Spine* 1985;10:150-3.
 10. Pearcy MJ, Tibrewal SB. Axial rotation and lateral bending in the normal lumbar spine measured by three-dimensional radiography. *Spine* 1984;9:582-7.
 11. Dvorák J, Panjabi MM, Chang DG, Theiler R, Grob D. Functional radiographic diagnosis of the lumbar spine. Flexion-extension and lateral bending. *Spine* 1991;16:562-71.
 12. Fitzgerald GK, Wynveen KJ, Rheault W, Rothschild B. Objective assessment with establishment of normal values for lumbar spinal range of motion. *Phys Ther* 1983;63:1776-81.
 13. Dillard J, Trafimow J, Andersson GB, Cronin K. Motion of the lumbar spine. Reliability of two measurement techniques. *Spine* 1991;16:321-4.
 14. Ng JK, Kippers V, Richardson CA, Parnianpour M. Range of motion and lordosis of the lumbar spine: reliability of measurement and normative values. *Spine* 2001;26:53-60.
 15. Bell JA, Stigant M. Development of a fibre optic goniometer system to measure lumbar and hip movement to detect activities and their lumbar postures. *J Med Eng Technol* 2007;31:361-6.
 16. Wong KW, Luk KD, Leong JC, Wong SF, Wong KK. Continuous dynamic spinal motion analysis. *Spine* 2006;31:414-9.
 17. Gajdosik RL, Albert CR, Mitman JJ. Influence of hamstring length on the standing position and flexion range of motion of the pelvic angle, lumbar angle, and thoracic angle. *J Orthop Sports Phys Ther* 1994;20:213-9.
 18. Hayes MA, Howard TC, Gruel CR, Kopta JA. Roentgenographic evaluation of lumbar spine flexion-extension in asymptomatic individuals. *Spine* 1989;14:327-31.
 19. Alaranta H, Hurri H, Heliövaara M, Soukka A, Harju R. Flexibility of the spine: normative values of goniometric and tape measurements. *Scand J Rehabil Med* 1994;26:147-54.
 20. Petersen CM, Johnson RD, Schuit D, Hayes KW. Intraobserver and interobserver reliability of asymptomatic subjects' thoracolumbar range of motion using the OSI CA 6000 Spine Motion Analyzer. *J Orthop Sports Phys Ther* 1994;20:207-12.
 21. Putto E, Tallroth K. Extension-flexion radiographs for motion studies of the lumbar spine. A comparison of two methods. *Spine* 1990;15:107-10.
 22. 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;73:626-31.
 23. Russell P, Pearcy MJ, Unsworth A. Measurement of the range and coupled movements observed in the lumbar spine. *Br J Rheumatol* 1993;32:490-7.
 24. Littlewood C, May S. Measurement of range of movement in the lumbar spine-what methods are valid? A systematic review. *Physiotherapy* 2007;93:201-11.
 25. Teyhen DS, Flynn TW, Bovik AC, Abraham LD. A new technique for digital fluoroscopic video assessment of sagittal plane lumbar spine motion. *Spine* 2005;30:E406-13.
 26. Kılınçer C, Cigali BS, Hamamcıoğlu MK, Çobanoğlu S. Omurgada hareket ölçümleri. *Türk Nöroşirürji Derg* 2002;12:119-24.
 27. Schreiber TU, Anders C, Uhlemann C, Bak P, Smolenski U, Scholle H.C. Mobility of lumbar spine recorder by three-dimensional motion analysis in patients with low back pain and controls. In: Vleeming A, Mooney V, Tilscher H, Dorman T, Snijders C, editors. *Proceedings of the 3rd interdisciplinary world congress on low back and pelvic pain*; 1998 Nov 19-21; Vienna: Austria; 1998. p. 446-50.
 28. Wang SF, Teng CC, Lin KH. Measurement of cervical range of motion pattern during cyclic neck movement by an ultrasound-based motion system. *Man Ther* 2005;10:68-72.
 29. Dvir Z, Prushansky T. Reproducibility and instrument validity of a new ultrasonography-based system for measuring cervical spine kinematics. *Clin Biomech* 2000;15:658-64.
 30. Lee RY, Wong TK. Relationship between the movements of the lumbar spine and hip. *Hum Mov Sci* 2002;21:481-94.