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Comparison of the Flexion-Relaxation Ratio of the Hamstring Muscle and Lumbopelvic Kinematics During Forward Bending in Subjects With Different Hamstring Muscle Flexibility

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Abstract

Background: Flexion-relaxation phenomenon (FRP) was a term which refers to a sudden onset of myoelectric silence in the erector spinae muscles of the back during standing full forward flexion. Hamstring muscle length may be related to specific pelvic and trunk movements. Many studies have been done on the FRP of the erector spinae muscles. However, no studies have yet investigated the influence of hamstring muscle flexibility on the FRP of the hamstring muscle and lumbopelvic kinematics during forward bending.

Objects: The purpose of this study was to examine the flexion-relaxation ratio (FRR) of the hamstring muscles and lumbopelvic kinematics and compare them during forward bending in subjects with different hamstring muscle flexibility.

Methods: The subjects of two different groups were recruited using the active knee extension test. Group 1-consisted of 13 subjects who had a popliteal angle under 30°; Group 2-consisted of 13 subjects who had a popliteal angel above 50°. The kinematic parameters during the trunk bending task were recorded using a motion analysis system and the FRRs of the hamstring muscles were calculated. Differences between the groups were identified with an independent t-test.

Results: The subjects with greater hamstring length had significantly less lumbar spine flexion movement and more pelvic flexion movement. The subjects with greater pelvic flexion movement had a higher rate of flexion relaxation during full trunk bending ($p<.05$).

Conclusion: The results of this study suggest that differences in hamstring muscle flexibility might cause changes in people's hamstring muscle activity and lumbopelvic kinematics.

Key Words: Flexion-relaxation ratio; Hamstring; Lumbopelvic kinematics.

Introduction

The hamstring muscle complex is composed of three muscles that arise from part of the ischial tuberosity. Hamstring shortness is a common finding in low back pain (LBP) patients (Nourbakhsh et al, 2002). Hamstring muscle extensibility may be associated with specific pelvic and trunk postures (Gajdosik et al, 1994). Because the hamstring muscles originate on the ischial tuberosity of the pelvis, a decreased extensibility will affect the range of motion and posture of the pelvis (Congdon et al, 2005; Dewberry et al, 2003). Decreased hamstring muscle extensibility reduces the pelvic flexion range of motion during forward bending movement with the knees straight (Gajdosik et al, 1992).

Pelvic flexion range has been suggested to be related to LBP due to the anatomical proximity of the

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pelvic and lumbar areas, and many authors interested in LBP have examined the association between the pelvic and lumbar areas (Harris-Hayes et al, 2009). Inadequate pelvic mobility is related to greater LBP severity (Mellin, 1988). Restricted pelvic flexion movement can be a risk factor that contributes to musculoskeletal pain syndromes, and alters mechanical forces, possibly leading to overstress in the lumbopelvic area (Ellison et al, 1990; Shum et al, 2007; Wong and Lee, 2004). Previous studies have highlighted the relationship between active pelvic flexion and LBP (Childs et al, 2004; Cibulka et al, 1998; Cibulka, 1999; Ellison et al, 1990; Fairbank et al, 1984; Flynn et al, 2002; Mellin, 1990). Several investigators have proposed that hip range of motion (ROM) measurements should be involved in studies with interventions targeting the lumbar vertebrae (Flynn et al, 2002; Hicks et al, 2005). Forward bending activities done by individuals with greater flexibility in the lumbopelvic area than in the hip joint will lead to compensatory lumbar flexion at the relatively flexible lumbopelvic area (Sahrmann, 2002).

The term flexion-relaxation phenomenon (FRP) was coined by Floyd and Silver (Floyd and Silver, 1955) to depict the tendency of the low back muscle to activate as an individual moves to bend forward, be quiet during full flexion, and reactivate during body extension, subsequently bringing the back to an upright standing posture (Schinkel-Ivy et al, 2014). The FRP has been known as a sign of lumbar neuromuscular alterations caused by LBP (Alschuler et al, 2009; Shirado et al, 1995). In the full flexion posture, the body weight is assisted mainly by a passively generated extension moment from the spinal ligaments, intervertebral discs, and passive components of the extensor muscle-tendon units (McGill. and Kippers, 1994). This process involves the shift of the play of the extension moment generator from the active component (muscle tissue) to the passive component (ligaments, discs and fascia) (Ning et al, 2011). In addition, recent research has reported that the FRP takes place during lifting (Dolan et al, 1994; Mathieu and Fortin, 2000; Toussaint et al, 1995), lateral bending (Raftopoulos et al, 1988), and sitting (Callaghan and Dunk, 2002). The FRP is changed by many factors, including the magnitude of applied load (Schultz et al, 1985), and the loading rate (Sarti et al, 2001), and differences have been announced between low back pain and healthy subjects (Ahern et al, 1988; Golding, 1952; Shirado et al, 1995). The FRP is also modified due to repeated trunk bending (Dickey et al, 2003). It was also found that an increase in knee flexion can decrease tension on the lumbar posterior tissues and result in a lag of the lumbar erector spinae muscle's FRP (Shin et al, 2004).

Eccentric hamstring actions are associated with the maintenance of the posterior pelvic tilt during forward bending. It may be likely that LBP patients have increased eccentric hamstring torque as an adaptive mechanism to stabilize the lumbo-pelvic region (Marshall et al, 2010).

Hamstring is an important stability muscle of the lower limb and its flexibility is important for maintaining normal posture and movement (Vadivelan and Priyaraj, 2015). The decrease of hamstring muscle flexibility produces a decrease of pelvic mobility that leads to an invariable biomechanical change in the pressure distribution in spine (Vadivelan and Priyaraj, 2015). Therefore, lower hamstring flexibility has been associated with postural deviations, gait limitations, increased risk of falls, and susceptibility to musculoskeletal injuries (Mayora-Vega et al, 2015). Recent study has suggested that an activation pattern similar to FRP is shown by the hamstring muscles (McGorry et al, 2001).

However, to the best of our knowledge, no studies have yet investigated the influence of hamstring muscle flexibility on the FRP of the hamstring muscle and lumbopelvic kinematics during forward bending. Therefore, the purpose of this study was to examine the flexion-relaxation ratio (FRR) of the hamstring muscles and lumbopelvic kinematics and compare them during forward bending in subjects with different hamstring muscle flexibility.

Methods

Subjects

A total of 35 participants volunteered to participate in the pretest. They were screened by a skilled physical therapist. Twenty-six subjects (n=26; 6 women and 20 men) were recruited to participate in this study. The active knee extension (AKE) test (Gajdosik and Lusin, 1983) was used to assess hamstring muscle length. The Popliteal angle was defined as the degree of knee flexion from terminal knee extension. Complete knee extension means a popliteal angle of 0°, and the lack of knee extension was measured with a bubble inclinometer (Figure 1). The AKE testing procedure was explained to all participants. The AKE measurements were taken for both knees. The inclusion criterion was subjects who had a popliteal angle under 30° (Group 1) or above 50° (Group 2). The 9 subjects who had a popliteal angle from 31° to 49° were excluded. People with any known orthopedic or neurological disorders were excluded. The general characteristics of the subjects are shown in Table 1. This study was approved by the Yonsei University Wonju institutional review board (approval number: 1041849-201704-BM-020-01).

Electromyography (EMG)

Each subject's skin was cleaned with an alcohol swab. The electrodes were placed over the skin of right and left hamstrings (biceps femoris, BF) at the midpoint of the distance between the ischial tuberosity and the fibular head (Leinonen et al, 2000). The raw EMG signals were band-pass filtered between 20 and 450 ㎐, and sampled at 1000 ㎐. The EMG signals were processed into the root-mean-square (RMS) moving window of the 300-㎳ duration of the EMG data. We calculated the FRR as the maximum EMG during forward flexion (a) divided by the minimum resting (fully flexed) EMG (b) (Ahern et al, 1988; Watson et al, 1997). Electromyography values were calculated as the 1 second average RMS EMG around the maximum EMG levels detected during flexion and at the minimum level detected during the rest time. Using EMG values as ratios has the benefit of providing a normalized EMG value, which might provide the ability to compare FRRs over time and across people. This method has moderate to excellent within and between session reliability (Watson et al, 1997).

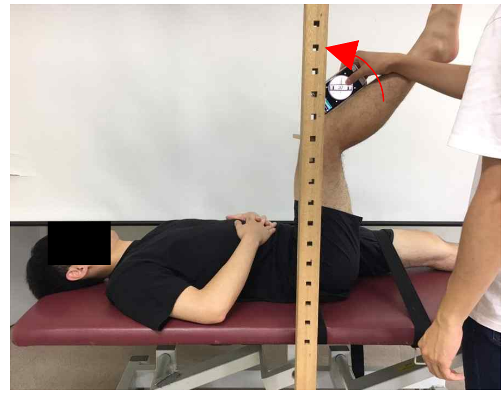

Figure 1. Active knee extension test (AKEtest).

Kinematic data

The EMG system (EMG, Noraxon Inc., AZ, USA) was synchronized with a motion analysis system. The motion analysis system (MyoMotion system,

Table 1. General characteristics of the subjects

Parameters	Group 1[a] (n_1=13)	Group 2[a] (n_2=13)	p
Age (years)	22.8±1.7	23.4±2.0	.423
Height (㎝)	169.6±6.4	172.3±9.1	.409
Weight (㎏)	68.4±13.8	66.5±13.3	.721
Rt Popliteal angle (°)	17.84±7.5	53.8±3.6	.001
Lt Popliteal angle (°)	18.5±8.1	53.9±2.7	.001
Dominant leg	Right=13 / Left=0	Right=13 / Left=0	

[a]mean±standard deviations.

Noraxon Inc., St. AZ, USA) was used to record the kinematic data. MyoMotion sensors were attached to the subject's lower thoracic spine, pelvis and both thighs at the center of the spinous processes of the twelfth thoracic and first sacral vertebrae, and at the midpoint between the lateral femoral epicondyle and the greater trochanter of the femur (Figure 2). The fascia over the spinous processes has a firm fix ation to bone (Lundberg, 1996), so skin movement will follow bone movement more closely than in other regions. All sensors were fastened to the skin over-lying these bony landmarks using special fixation straps, double-sided adhesive tape, and elastic straps. The kinematic data consisted of the lumbar and pel-vic flexion angles. In the sagittal plane, the Lumbar flexion angle was defined as the mediolateral-axis angle between the lumbar spine and the pelvis; the pelvic flexion angle was defined as the medio-lateral-axis angle between the pelvis and the femur.

Experimental protocol

The trunk forward bending task (Kim et al, 2013) consisted of natural standing, bending (trunk flexion), hanging (trunk full flexion), returning, and relaxed standing periods. The subjects were allowed to prac-tice the required movements to familiarize themselves with the experimental tasks. A counted time signal was used to pace the movement. The subjects stood on a line labeled on the floor with their arms by their sides and the their feet at pelvis-width apart. First, the subjects were required to stand naturally for 3 seconds and then to bend their trunk forward as far as possible without flexing their knees and let their arms hang freely for 3 seconds. Second, they were instructed to hang in the fully flexed position for 3 seconds with the metronome. Third, they were asked to go back to the upright position for 3 seconds. Finally, the subjects were required to sustain a natural standing position for 3 seconds (Figure 3). Each activity was repeated three times. The mean score was used in the kinematic and electromyo-graphical data analysis.

Figure 2. Location of the electrodes and myomotion sensors.

Figure 3. Postures adopted during the forward bending tasks.

Statistical analysis

The SPSS statistical package version 18.0 was used for the statistical analyses. All data were tested for normal distribution with the Shapiro-Wilk nor-mality test (EMG and kinematic data of the hip and lumbar). All variables were confirmed to be normally distributed; thus, parametric statistics were used. The significance of the differences between the two groups was evaluated using the independent t-test. p values less than .05 were used for the statistical tests.

Results

The FRRs of the hamstring muscles and lumbopelvic kinematics between two groups

In the subjects with greater hamstring muscle flexibility (Group 1), the pelvic flexion showed a more range of motion than the lumbar flexion. The FRRs of the hamstring muscles were significantly higher in the subjects with greater hamstring muscle flexibility group (3.85±1.78) than in the subjects with lower hamstring muscle flexibility group (.93±.11) (Table 2).

Discussion

Diverse methods have been suggested for the quantification of FRP, comprising 4 general categories of visual inspection, statistical, threshold, and ratio. Ratio criteria identified FRP with high sensitivity and may be appropriate for use in either research or clinical settings. (Schinkel-Ivy, 2013).

The major results of this study indicate that the FRR of the hamstring muscle was significantly decreased in the lower hamstring muscle flexibility group when compared to the greater hamstring muscle flexibility group. In the subjects with lower hamstring muscle flexibility, the maximal lumbar flexion was greater and the maximal hip flexion was lower than in the other subjects. This study also confirmed that the FRP occurs in hamstrings during terminal hip flexion, which follows previously reported patterns (Sihvonen, 1997). The tightness of the hamstring muscles may have been overactivated during the hanging period, as a consequence of increased eccentric muscle activity.

This study also shows that subjects with more flexible hamstring muscles have a large amount of biceps femoris muscle relaxation during the hanging period, and the tightened hamstring muscle is related to a greater muscle activation of the hamstrings during the hanging period. During the forward bending period, the values were 29.32±8.31 μV in the group 1 and 33.19±6.77 μV in the group 2, but this difference was not statistically significant ($p>.05$).

Several authors have found that shortness of the hamstrings and lower pelvic flexion are related to the presence of LBP and have recommended using hamstring stretching to obtain more flexibility and boost the cooperation of the pelvic motion in trunk flexion-extension (Cailliet, 1995; Esola et al, 1996).

It has been commonly assumed that when two body parts move, the more mobile body segment will move first, and this was described as compensatory relative flexibility by Sahrmann (2002). Two variations in the degree of lumbar to pelvic flexion motion and changes in hamstring flexibility have been

Table 2. Maximal angular displacements and FRR of the hamstring muscle during the trunk bending task

	Group 1[a]	Group 2[a]	p
Maximal Rt pelvic flexion (°)	69.70±6.28	41.21±7.39	.001
Maximal Lt pelvic flexion (°)	69.37±6.93	42.61±7.47	.001
Maximal lumbar flexion (°)	44.99±9.85	54.69±9.42	.017
Rt hamstring muscle activity during trunk flexion (uV/s)	29.32±8.31	33.19±6.77	.200
Rt hamstring muscle activity during trunk full flexion (uV/s)	9.13±3.87	35.55±10.43	.001
Lt hamstring muscle activity during trunk flexion (uV/s)	32.86±3.79	35.13±5.86	.250
Lt hamstring muscle activity during trunk full flexion (uV/s)	10.65±5.02	39.93±18.07	.001
FRR of Rt hamstring	3.85±1.78	0.93±0.11	.001
FRR of Lt hamstring	3.55±1.61	0.93±0.28	.001

[a]mean±standard deviatioins.

demonstrated in LBP patients (Esola et al, 1996). It may be that a positive correlation exists between hamstring shortness and lumbar motion and negative correlation between hamstring shortness and hip motion.

One of the three subsystems of the spinal stabilizing system is a passive system: the spinal column, which is comprised of ligaments (spinal ligaments, discs annulus and facet capsules), vertebrae and the remaining two are the active and neural systems: the spinal muscles and the neuromuscular control unit (Panjabi, 2006). Uncountable mechanoreceptors lie in the spinal ligaments (Edgar, 2007; Sekine et al, 2001), facet capsules (McLain, 1994; Yamashita et al, 1990) and disc annulus (Edgar, 2007). Passive systems are deformed by the application of repeated stretching or tensile stress; this deformation creates information from the mechanoreceptors encompassed within them and this information decreases muscle activity (Holm et al, 2002).

The results of this study show how subjects with having lower hamstring flexibility are less movable at the pelvic level and more movable at the lumbar spine. In the higher movable condition of the lumbar spine in the lower hamstring flexibility group, the ligaments of the lumbar spine undergo lengthening and reduced tension. Therefore, passive structures rather than the spinal stabilizing muscles provide spinal stability and the ligaments of the lumbar spine may be overstretched. The lengthening of ligamentous structures can cause a meaningful reduction in the activation of the multifidus through mechanoreceptor desensitization (Solomonow et al, 1999).

There is evidence from animal studies that the stimulation of the ligaments of the spine results in spinal muscle firing (Solomonow et al, 1999; Solomonow et al, 2002). Decreased sensitivity of the ligament mechanoreceptors results in decreased muscle activity. One study observed that the creep produced in viscoelastic tissues by the imposition of cyclic loading causes desensitization of the mechanoreceptors. Other studies have observed that creep developed in the viscoelastic structures indicates that micro-damage developed in the collagen fibers (Frank et al., 1985; Soslowskyet al., 2000), which creates a notable decrease in muscle activity and, as a consequence, greater susceptibility to instability and possible injury (Solomonow et al, 1999).

The forward bending of the trunk allows pelvic anterior rotation in combination with lumbar flexion. The shortness of the hamstring muscle may have been eccentrically hyper-activated during the forward bending movement, which, in turn, posteriorly rotates the pelvis. A posterior pelvic rotation reduces the lumbar lordotic curve through the flexion of the lumbar spine, causes posterior movement of the nucleus pulposus, and increases the diameter of the intervertebral foramina (Neumann, 2002). Furthermore, shortened hamstring muscles are related to slumped sitting, because a slumped sitting posture can produce pelvic posterior tilting. Slumped sitting decreases the activation of the spinal stabilizing muscles (O'Sullivan et al, 2002) and aggravates loading on the intervertebral disc (Macintosh et al, 1993) and soft tissues. Generally, it is strongly accepted that passive postures like slumped sitting exacerbate chronic low back pain (O'Sullivan, 2000).

This study has several limitations. Interpretations of the results of our study are limited to our subjects, who were all university students in their early 20s. The findings of this study cannot be generalized to the entire population. We consider the lack of LBP patients group is a limitation of our study. We hope that future studies will account for these limitations.

Our results suggest that forward bending movements produce overuse of the lumbar spine in people with lower hamstring muscle flexibility, which produces mechanoreceptor desensitization in the ligaments of the spine and inactivity of the spinal stabilizing muscle, therefore, this might be connected to LBP. So, we suggest that clinicians attempt to recover normal hamstring muscle flexibility in the LBP patients. This possibility should be addressed in future studies of LBP patients.

Conclusion

This study has shown that significant differences were observed in the FRR of the hamstring muscles and lumbopelvic kinematics between the subjects with different hamstring muscle flexibility during forward bending movement. Hamstring muscle flexibility have an influence on lumbo-pelvic kinematics during trunk forward bending. The flexibility of the pelvis seems to influence the patterns of the activation of hamstring muscles during forward bending. Peculiarly, subjects that are more flexible in their hamstring muscles show a greater degree of flexion relaxation and pelvic flexion at maximum flexion.

References

Ahern DK, Follick MJ, Council JR, et al. Comparison of lumbar paravertebral EMG patterns in chronic low-back pain patients and non-patient controls. Pain. 1988;34(2):153-160.

Alschuler KN, Wiggert RE, Haig AJ, et al. Flexion-relaxation and clinical features associated with chronic low back pain: A comparison of different methods of quantifying flexion-relaxation. Clin J Pain. 2009;25(9):760-766.

Cailliet R. Low Back Pain Syndrome. 5th ed. Philadelphia, F.A., Davis Co. 1995;17-55.

Callaghan JP, Dunk NM. Examination of the flexion relaxation phenomenon in erector spinae muscles during short duration slumped sitting. Clin Biomech (Bistol, Avon). 2002;17(5):353-360.

Childs JD, Fritz JM, Flynn TW, et al. A clinical prediction rule to identify patients with low back pain most likely to benefit from spinal manipulation: A validation study. Ann Intern Med. 2004;141(12):920-928.

Cibulka MT, Sinacore DR, Cromer GS, et al. Unilateral hip rotation range of motion asymmetry in patients with sacroiliac joint regional pain. Spine (Phila Pa, 1976). 1998;23(9):1009-1015.

Cibulka MT. Low back pain and its relation to the hip and foot. J Orthop Sports Phys Ther. 1999;29(10):595-601.

Congdon R, Bohannon R, Tiberio D. Intrinsic and imposed hamstring length influence posterior pelvic rotation during hip flexion. Clin Biomech (Bristol, Avon). 2005;20(9):947-951.

Dickey JP, McNorton S, Potvin JR. Repeated spinal flexion modulates the flexion-relaxation phenomenon. Clin Biomech (Bristol, Avon). 2003;18(9):783-789.

Dewberry MJ, Bohannon RW, Tiberio D, et al. Pelvic and femoral contributions to bilateral hip flexion by subjects suspended from a bar. Clin Biomech (Bristol, Avon). 2003;18(6):484-499.

Dolan P, Mannion AF, Adams MA. Passive tissues help the back muscles to generate extensor moments during lifting. J Biomech. 1994;27(8):1077-1085.

Edgar MA. The nerve supply of the lumbar intervertebral disc. J Bone Joint Surg Br. 2007;89(9):1135-1139.

Ellison JB, Rose SJ, Sahrmann SA. Patterns of hip rotation range of motion: acomparison between healthy subjects and patients with low back pain. Phys Ther. 1990;70(9):537-541.

Esola, MA, McClure PW, Fitzgerald GK, et al. Analysis of lumbar spine and hip motion during forward bending in subjects with and without a history of low back pain. Spine (Phila Pa, 1976) 1996;21(1):71-78.

Fairbank JC, Pynsent PB, Van Poortvliet JA, et al. Influence of anthropometric factors and joint laxity in the incidence of adolescent back pain. Spine (Phila Pa, 1976). 1984;9(5):461-464.

Floyd WF, Silver PHS. The function of erector spinae muscles in certain movements and postures in man. J Physiol. 1955;129:184-203.

Floyd WF, Silver PH. Function of the erectores spinae in flexion of the trunk. Lancet. 1951;1(6647):133-134.

Flynn T, Fritz J, Whitman J, et al. A clinical prediction rule for classifying patients with low back pain who demonstrate short-term improvement with spinal manipulation. Spine (Phila Pa, 1976). 2002;27(24):2835-2843.

Frank C, Amiel D, Woo SL, et al. Normal ligament properties and ligament healing. Clin Orthop Rel at Res. 1985;(196):15-25.

Gajdosik GL, Lusin G. Hamstring muscle tightness. Reliability of an active knee-extension-test. Phys Ther. 1983;63(7):1085-1090.

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(4):213-219.

Gajdosik RL, Hatcher CK, Whitsell S. Influence of short hamstring muscles on the pelvis and lumbar spine in standing and during the toe-touch test. Clin Biomech (Bristol, Avon). 1992;7(1):38-42.

Golding JSR .Electromyography of the erector spinae in low back pain. Postgrad Med J. 1952;28:401-406.

Harris-Hayes M, Sahrmann SA, Van Dillen LR. Relationship between the hip and low back pain in athletes who participate in rotation-related sports. J Sport Rehabil. 2009;18(1):60-75.

Hicks GE, Fritz JM, Delitto A, et al. Preliminary development of a clinical prediction rule for determining which patients with low back pain will respond to a stabilization exercise program. Arch Phys Med Rehabil. 2005;86(9):1753-1762.

Holm S, Indahl A, Solomonow M. Sensorimotor control of the spine. J Electromyogr Kinesiol. 2002; 12:219-234.

Kim MH, Yi CH, Kwon OY, et al. Comparison of lumbopelvic rhythm and flexion-relaxation response between 2 different low back pain subtypes. Spine. 2013;38(15):1260-1267.

Leinonen V, Kankaanpa¨a¨ M, Airaksinen O, et al. Back and hip extensor activities during trunk flexion/extension: Effects of low back pain and rehabilitation. Arch Phys Med Rehabil. 2000; 81(1):32-37.

Lundberg A. On the use of bone and skin markers in kinematics research. Hum Mov Sci. 1996; 15(3):411-422.

Macintosh JE, Bogduk N, Pearcy MJ. The effects of flexion on the geometry and actions of the lumbar erector spinae. Spine (Phila Pa, 1976). 1993; 18:884-893.

Marshall PW, Mannion J, Murphy BA. The eccentric, concentric strength relationship of the hamstring muscles in chronic low back pain. J Electromyogr Kinesiol. 2010;20(1):39-45. https://doi.org/10.1016/j.jelekin.2009.04.005

Mathieu PA, Fortin M. EMG and kinematics of normal subjects performing trunk flexion/extensions freely in space. J Electromyogr Kinesiol. 2000; 10(3):197-209.

Mayora-Vega D, Merino-Marban R, Garcia-Romero JC. Validity of sit and reach with plantar flexion test in children aged 10-12 years. RIMCAFD. 2015;15(59):577-591.

McGill SM, Kippers V. Transfer of loads between lumbar tissues during the flexion relaxation phenomenon. Spine (Phila Pa, 1976). 1994;19(19): 2190-2196.

McGorry RW, Hsiang SM, Fathallah FA et al. Timing of activation of the erector spinae and hamstrings during a trunk flexion and extension task. Spine (Phila Pa, 1976). 2001;26(4):418-425.

McLain RF. Mechanoreceptor endings in human cervical facet joints. Spine (Phila Pa, 1976). 1994;19: 495-501.

Mellin G. Correlations of hip mobility with degree of back pain and lumbar spinal mobility in chronic low-back pain patients. Spine (Phila Pa, 1976). 1988;13:668-670.

Mellin G. Decreased joint and spinal mobility associated with low back pain in young adults. J Spinal Disord. 1990;3(3):238-243.

Neumann DA. Kinegiology of the Musculoskeletal System: Foundations for physical rehabilitation, 1st ed., St Louis, Mosby, 2002:307-423.

Ning X, Haddad O, Jin S, et al. Influence of asymmetry on the flexion relaxation response of the low back musculature. Clin Biomech (Bistol, Avon). 2011;26(1):35-39. https://doi.org/10.1016/j.clinbiomech.2010.08.012

Nourbakhsh MR, Arab AM. Relationship between mechanical factors and incidence of low back pain. J Orthop Sports Phys Ther. 2002;32(9):447-460.

O'Sullivan PB, Grahamslaw KM, Kendell M et al. The effect of different standing and sitting postures on trunk muscle activity in a pain-free population. Spine (Phila Pa, 1976). 2002;27:1238-1244.

O'Sullivan PB. Lumbar segmental 'instability': Clinical presentation and specific stabilizing exercise management. Man Ther. 2000;5(1):2-12.

Raftopoulos DD, Rafko MC, Green M, et al. Relaxation phenomenon in lumbar trunk muscles during lateral bending. Clin Biomech (Bistol, Avon). 1988;3(3):166-172. https://doi.org/10.1016/0268-0033(88)90063-0

Sahrmann SA. Diagnosis and Treatment of Movement Impairment Syndromes. 1st ed. St. Louis. Mosby. 2002:121-143.

Sarti MA, Lison JF, Monfort M, et al. Response of the flexion-relaxation phenomenon relative to the lumbar motion to load and speed. Spine (Phila Pa, 1976). 2001;26(18):E421-E426.

Schultz AB, Haderspeck-Grib K, Sinkora G, et al. Quantitative studies of the flexion-relaxation phenomenon in the back muscles. J Orthop Res. 1985;3(2):189-197.

Schinkel-Ivy A, Nairn BC, Drake JD. Evaluation of methods for the quantification of the flexion-relaxation phenomenon in the lumbar erector spinae muscles. J Manipulative Physiol Ther. 2013;36(6):349-358. https://doi.org/10.1016/j.jmpt.2013.05.017

Schinkel-Ivy A, Nairn BC, Drake JDM. Quantification of the Lumbar flexion relaxation phenomenon: Comparing outcomes of lumbar erector spinae and superficial lumbar multifidus in standing full trunk flexion and slumped sitting postures. J Manip Physiol Ther. 2014;37(7):494-501. https://doi.org/10.1016/j.jmpt.2014.07.003

Sekine M, Yamashita T, Takebayashi T et al. Mechanosensitive afferent units in the lumbar posterior longitudinal ligament. Spine (Phila Pa, 1976). 2001;26(14):1516-521. https://doi.org/10.1097/00007632-200107150-00003

Shin G, D'Souza C, Liu Y. Creep and fatigue development in the low back in static flexion. Spine (Phila Pa, 1976). 2009;34:1873-1878. https://doi.org/10.1097/brs.0b013e3181aa6a55

Shin G, Shu Y, Li Z, et al. Influence of knee angle and individual flexibility on the flexion-relaxation response of the low back musculature. J Electromyogr Kinesiol. 2004;14(4):485-494.

Shirado O, Ito T, Kandea K, et al. Flexion-relaxation phenomenon in the back muscles. A comparative study between healthy subjects and patients with chronic low back pain. Am J Phys Med Rehabil. 1995;74(2):139-144.

Shum GL, Crosbie J, Lee RY. Three-dimensional kinetics of the lumbar spine and hips in low back pain patients during sit-to-stand and stand-to-sit. Spine (Phila Pa, 1976). 2007;32(7):E211-E219.

Sihvonen T. Flexion relaxation of the hamstring muscles during lumbarpelvic rhythm. Arch Phys Med Rehabil. 1997;78(5):486-490.

Solomonow M, Zhou BH, Baratta RV, et al. Biomechanics of increased exposure to lumbar injury caused by cyclic loading: Part 1. Loss of reflexive muscular stabilization. Spine (Phila Pa, 1976). 1999;24(23):2426-2434.

Solomonow M, Zhou BH, Baratta RV, et al. Neuromuscular disorders associated with static lumbar flexion: a feline model. J Electromyogr Kinesiol. 2002;12(2):81-90.

Soslowsky L, Thomopoulos S, Tun S, et al. Overuse activity injury in supraspinatus tendon in an animal model: A histologic and biomechanical study. J Shoulder Elbow Surg. 2000;9(2):79-84.

Toussaint HM, de Winter AF, de Haas Y, et al.

Flexion relaxation during lifting: implications for torque production by muscle activity and tissue strain at the lumbo-sacral joint. J Biomech. 1995;28(2):199-210.

Vadivelan K, Priyaraj B. influence of two different sitting postures on hamstring muscle flexibility in school going chilidren. Int J Physiother. 2015;2(2):459-464.

Watson PJ, Booker CK, Main CJ, et al. Surface electromyography in the identification of chronic low back pain patients: The development of the flexion relaxation ratio. Clin Biomech (Bistol, Avon). 1997;12(3):165-171.

Wong TK, Lee RY. Effects of low back pain on the relationship between the movements of the lumbar spine and hip. Hum Mov Sci. 2004;23(1):21-34.

Yamashita T, Cavanaugh JM, el-Bohy AA, et al. Mechanosensitive afferent units in the lumbar facet joint. J Bone Joint Surg Am. 1990;72(6):865-870.

Zuriaga DS, Pérez CA, Roig GB. Lumbopelvic flexibility modulates neuromuscular responses during trunk flexion-extension. J Electromyogr Kinesiol. 2016;28:152-157. https://doi.org/10.1016/j.jelekin.2016.04.007

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