Extensibility and Stiffness of the Hamstrings in Patients With Nonspecific Low Back Pain

Jan P.K. Halbertsma, PhD, Ludwig N.H. Göeken, MD, PhD, At L. Hof, PhD, Johan W. Groothoff, PhD, Willem H. Eisma, MD

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Objective: To investigate the extensibility and stiffness of the hamstrings in patients with nonspecific low back pain (LBP).

Design: An experimental design.

Setting: A university laboratory for human movement analysis in a department of rehabilitation medicine.

Participants: Forty subjects, a patient group (20) and a healthy control group (20).

Interventions: Subjects laid supine on an examination table with a lift frame, with left leg placed in a sling at the ankle. Straight leg raising, pulling force, and activity of hamstring and back muscles were recorded with electrodes. Patients indicated when they experienced tension or pain.

Main Outcome Measures: The lift force, leg excursion, pelvic-femoral angle, first sensation of pain, and the electromyogram of the hamstrings and back muscles measured in an experimental straight-leg raising set-up.

Results: The patient group showed a significant restriction in range of motion (ROM) and extensibility of the hamstrings compared with the control group. No significant difference in hamstring muscle stiffness can be assessed between both groups.

Conclusion: The restricted ROM and the decreased extensibility of the hamstrings in patients with nonspecific LBP is not caused by increased muscle stiffness of the hamstrings, but determined by the stretch tolerance of the patients.

Key Words: Hip joints; Leg; Lordosis; Low back pain; Muscles; Range of motion, articular; Rehabilitation.

IN REHABILITATION MEDICINE, assessment of posture and movement disorders is an important part of the physical examination. The potential movement of the joints is related to the ability to perform functional tasks and is considered of crucial importance. In this context, it is of clinical interest to measure possible loss of movement.[1] Measuring range of motion (ROM) is a fundamental evaluation procedure. The results can be used to quantify limitations in ROM, to decide on appropriate interventions, and then to record the effectiveness of therapy.[2] In subjects with a limited ability to bend forward from the standing position while holding the knees in extension, the finger-to-ground distance is measured. A similar test can be performed with passive straight-leg raising (SLR); in SLR, the maximum angle between the straight leg and the longitudinal axis of the trunk is measured. When diminished ROM of the leg is observed and the hip joint has normal function and neurologic symptoms are absent, clinicians are inclined to think of short, too short, or shortened muscles. Generally, this limitation of motion in healthy subjects is not considered abnormal. The usual procedure is to stretch the affected muscles to increase the ROM.[3-6]

Rehabilitation medicine has been involved in the development and application of effective noninvasive treatment programs for patients with low back pain (LBP). Some rehabilitation programs have shown a high rate of success.[7] The object of these programs was to return the back-injured subjects to their full working capacity by restoring function, reducing pain, or both. Stretching exercises, used to regain or to improve ROM and functioning after trauma or periods of immobilization, are some of the common techniques used by physical therapists to treat LBP.[7-10]

A common phenomenon in patients with LBP is their inability to touch the ground with their fingers. If the hip function in patients does not deviate from the clinical norm and neurologic symptoms are absent, it is common practice to perform subsequently a passive SLR test. While the patient is supine, the straight leg is raised as far as possible. The test outcome can be interpreted with respect to the maximum lift angle of the leg with the horizontal plane and the pain that is provoked. Generally, the outcome of the SLR test is considered normal if the leg can be lifted 80° or more without pain.[11,12] Subjects with both a finger-to-ground distance equal to or smaller than 0cm and a lift angle of 80° or more are considered flexible.[13] If the lift angle is less than 80° without pain or with pain only in the dorsal part of the thigh, the limitation of motion is usually attributed to an insufficient elasticity of the hamstring muscles. Stiff muscles, short muscles, diminished suppleness, and decreased elasticity are adjectives connected with this inability.

If the pain is assessed as nonspecific, limited ROM can be attributed to the intervertebral and sacroiliac joints, facet pain, and ligaments or back muscles.[11,13,14] Nonspecific LBP (NSLBP), in general, refers to pain without a clear organic cause. Patients referred to rehabilitation medicine with NSLBP have previously been examined by a neurologist and a radiologist. If the pain is assessed as specific, limited ROM is usually attributed to pathology of the sciatic nerve or its composing nerve roots.[13,14]

In patients with NSLBP, it is difficult to assess with a clinically performed manual test whether the limited ROM can be attributed to increased muscle stiffness or decreased extensibility of the hip or the back muscles. It is also not known whether these muscles are active or passive during manual

From the Department of Rehabilitation Medicine (Halbertsma, Göeken, Hof, Eisma), Human Movement Sciences (Halbertsma, Göeken), Medical Physiology (Hof), University Hospital Groningen; and Northern Centre for Healthcare Research (Groothoff), Groningen, The Netherlands.

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Reprint requests to Jan P.K. Halbertsma, PhD, Dept of Rehabilitation Medicine, University Hospital Groningen, Hanzeplein 1, 9700 BV Groningen, The Netherlands, e-mail: *j.p.k.halbertsma@rev.azg.nl*.

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Table 1: Personal Data of the FG, SG, and PG

Variable	FG (*n* = 8)	SG (*n* = 12)	PG (*n* = 20)
Age (yr)	28.2 ± 7.63	29.4 ± 5.57	33.0 ± 11.01
Height (cm)	173.6 ± 7.52	178.2 ± 10.15	178.6 ± 11.10
Weight (kg)	68.4 ± 8.60	75.1 ± 11.31	77.8 ± 16.88
FGD (cm)	0.0 ± 0.00	15.1 ± 4.69	30.8 ± 18.74*

NOTE. Data presented as mean ± standard deviation (SD).
Abbreviation: FGD, finger-to-ground distance.
* Significant for SG and PG, $p < .05$.

testing. Patients with NSLBP show similar ROM and finger-to-ground distance as subjects with short hamstrings. In subjects with short hamstrings, stretching exercises result in increased ROM and no changes in muscle stiffness.[3-5] Stretching exercises are also applied in patients with NSLBP.

We hypothesized that, in patients with NSLBP, stretching exercises only can be applied when the hamstrings show similar behavior as in subjects with short hamstrings. This study sought to analyze the properties of the hamstring muscles in patients with NSLBP versus subjects with short hamstrings. Therefore, it was necessary to measure variables like ROM, extensibility of the hamstrings, muscle stiffness, electromyogram (EMG) response of the hamstrings, and perceived pain.

An instrumental version of the SLR test has been developed, called the instrumental straight-leg raising (ISLR).[11,12] The ISLR test enables simultaneous measurement of the leg excursion angle, pelvic-femoral angle, force to lift the leg, electric activity of the muscles (by EMG), flattening of the back, and the extent of leg excursion at which pain or tension is experienced. These variables provide for information on ROM, pelvic tilt, extensibility of the hamstrings and back muscles, muscle stiffness, lumbar lordosis, pain perception, defense reactions, and stretch tolerance.[3-5,11-14]

METHODS

Subjects

Subjects with LBP were selected randomly from the rehabilitation department and assigned to the patient group (PG). The following selection criteria had to be met: (1) NSLBP for at least 2 months; (2) finger-to-ground distance greater than 0cm; (3) a passive SLR angle of less than 80°, measured with a hand-held goniometer; (4) normal mobility of the hip; in the passive hip-flexion test with the knee fully flexed, the knee could almost touch the chest; (5) neurologic symptoms were absent; and (6) the electromyographic pattern of the muscles involved did not show an abnormal defense reaction.[14] Selected in this way, 20 subjects (12 men, 8 women) with LBP entered the experiment.

Twenty healthy volunteers (10 men, 10 women) from the faculty of medicine at our university participated in the experiment as a control group. To eliminate possible pathology, the following selection criteria had to be met: (1) normal mobility of the hip; (2) no history of neurologic or orthopedic disorders; and (3) no recent or chronic LBP or injuries of the lower extremities. Based on their ability to touch the ground with their fingers (finger-to-ground distance ≤ 0cm), 8 subjects entered the flexible group (FG). In 12 subjects, the finger-to-ground distance was greater than 0cm, and they were assigned to the stiff group (SG). Written informed consent was obtained from each subject before the study began. A description of the subjects is provided in table 1.

ISLR Test

The ISLR set-up consisted of an examination table with a lift-frame (fig 1). The subject was supine, with the left leg placed in a sling at the ankle that was connected to a force transducer attached to the lift-frame. The force transducer[a] recorded the pulling force necessary to lift the leg. The lift-frame was lifted by an electromotor with an angular velocity of 3°/s. The speed agreed approximately with the clinically performed manual SLR. The lift-frame axis could be moved vertically or horizontally, to make it coincident with the hip axis of the subject. Electrogoniometers[b] were situated on the lift-frame axis, hip joint, and knee joint to measure the angles involved. The lumbar lordosis was measured by a linear displacement potentiometer.[c] Bipolar surface electrodes[d] were placed on the hamstrings and back muscles to record muscle activity. The subject held a device with a push-button to

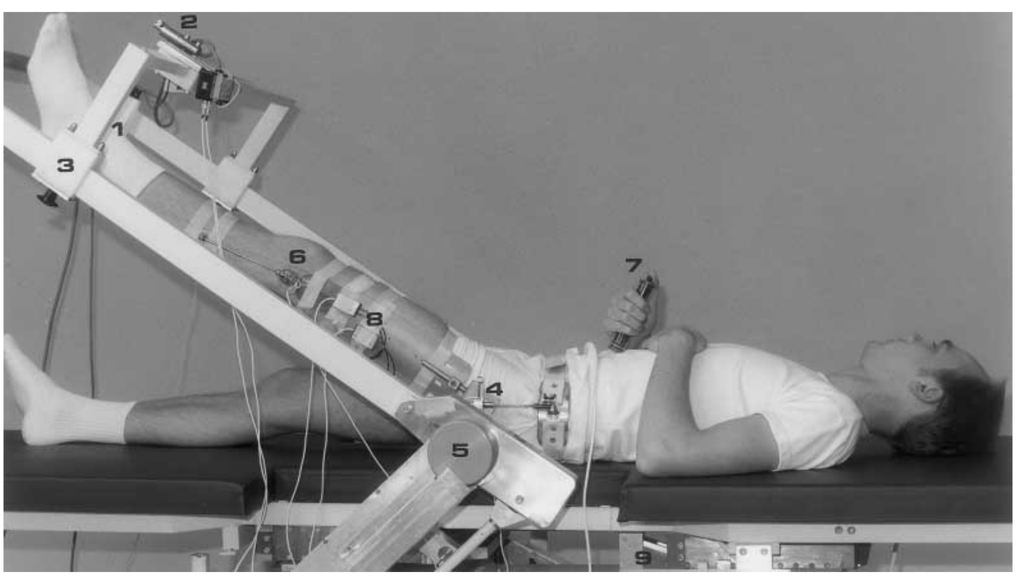

Fig 1. ISLR set-up: (1) sling, (2) force transducer, (3) lift-frame, (4) electrogoniometers on hip, (5) frame axis, (6) knee, (7) stretch tolerance indicator, and (8) electromyography amplifiers of hamstring muscles, and (9) lumbar lordosis potentiometer under the examination table.

indicate the instant he/she experienced tension or pain. Here, a brief exposition of the principles of the ISLR set-up is given.[3]

Angular rotations during SLR. The measured leg excursion could be divided into 2 components: rotation of the leg with respect to the pelvis, and the pelvic tilt. When the hip axis coincided with the axis of the lift-frame, the rotation of the leg was identical with the rotation of the lift-frame (fig 1). The angle of the leg with respect to the horizontal plane was measured by an electrogoniometer on the axis of the lift-frame and represented the leg excursion; the maximum of the angle was defined as the ROM of the leg. The pelvic-femoral angle was measured by an electrogoniometer on the hip joint and represented the elongation of the hamstrings; the maximum of the angle was considered the extensibility of the hamstrings. The pelvic tilt was found by subtracting the pelvic-femoral angle from the leg excursion angle; the maximum of this angle was considered the extensibility of the back muscles. The knee flexion was measured by an electrogoniometer to check if the leg had remained straight during ISLR. A schematic representation of the angles involved is presented in figure 2.

Lift force and muscle moments. The pulling force to lift the leg acted perpendicularly to the length axis of the leg at the ankle joint. Force consisted of a gravity component (the weight of the limb) and a stiffness component (the hamstrings muscle resistance). The hamstrings muscle moment could be calculated from the lift force and leg length. The stiffness of the muscle was defined as the calculated moment encountered at different joint angles. The slope of the moment-angle curve has been used to characterize muscle stiffness in normal subjects and patients.[3] The passive muscle stiffness referred to the absence of electric activity of the hamstrings during SLR.[4,5]

Lumbar lordosis. The vertical distance (h) between the lumbar spine and the horizontal plane was defined as the lumbar lordosis (fig 2). This position was generally found at the level of the third and fourth lumbar vertebrae.[11] By definition, the lordosis was 0 when the back was completely flat on the table. A flattening of the lumbar lordosis caused by the pelvic tilt could be measured SLR.

Pain sensation and stretch tolerance. During SLR, subjects were asked to indicate (by pushing a button) the beginning of pain or an unpleasant tension sensation in the dorsal part of the thigh off the knee (fig 1). This first sensation of pain was recorded as a function of the pelvic-femoral angle. Subjects were also instructed to push the button and to say "stop" when they could no longer tolerate more movement or stretch; at that point, the leg raise was stopped. The stretch tolerance was defined by the extensibility of the hamstrings. Note that the subjects stopped the leg raise.

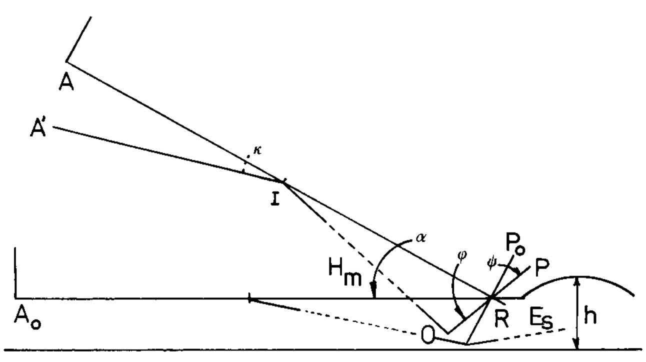

Fig 2. Model in a sagittal plane. The initial position, with the leg lying on the table, are given by RA_0 and RP_0. The angles are defined by: $\alpha = \angle A_0RA$, or the lift angle of the leg with respect to the horizontal, $\phi = \angle ORA$, or the pelvic-femoral angle, $\psi = \angle P_0RP$ or the tilting of the pelvis, and $\kappa = \angle A'IA$ or the angle of knee flexion. Abbreviations: R, hip axis; A, malleolus; RA, leg; RP, pelvis; A_0R, horizontal plane; O, origin of the hamstring muscles; I, insertion of hamstring muscles; H_m, hamstring muscles; E_s, direction of the erector spinae; h, lumbar lordosis.

EMGs of the hamstrings and back muscles. During SLR, the muscles subjected to elongation might react with involuntary eccentric contractions or reflex activity and voluntary contractions. Previous work from this laboratory has classified reactive muscle activity on hamstring stretch based on the electromyographic pattern as a normal or an abnormal defense reaction.[13-15] In the present study, a normal defense reaction was characterized by: (1) the onset of electromyographic activity close to the maximum leg excursion; (2) a gradual increase of the electromyographic activity with increasing leg raise, and the maximum value was reached at the maximum lift angle or ROM; (3) presence of electromyographic activity in back muscles or hamstrings; and (4) the onset of electromyographic activity was not simultaneous. An abnormal defense reaction was characterized by: (1) both an early onset and a fast increase in muscle activity; and (2) the early onset and fast increase of electromyographic activity was often present in all muscles simultaneously. Muscle stiffness could be influenced by muscle activity.[4,5] To measure if muscle activity was present, bipolar electromyography electrodes (type Ag/AgCl, 10-mm diameter) with a 25-mm electrode distance were placed on the hamstring muscles (semimembranosus, semitendinosus, biceps femoris [long head]), the gluteus maximus, and erector spinae. The presence of electromyographic activity was recorded as a function of the pelvic-femoral angle. Electromyographic-amplifiers[e] (input impedance, 1MΩ; common mode rejection, 80dB; frequency range, 20–600Hz) were used for electromyographic signal sampling. The raw electromyographic signals from the muscles were amplified (1500×), full-wave rectified, and low-pass filtered (I-EMG) with a time constant of .12 seconds.

Measuring Procedure and Protocol

With the subject prone on the examination table, electromyography electrodes were placed on the hamstrings and back muscles, all on the ipsilateral side. The subject was asked to extend the hip, and the electromyographic activity level was measured when the leg was just free of the table. To measure the reference activity of the erector spinae and the gluteus maximus, the subject was asked to extend the hip with the knee flexed. The gains of the electromyography amplifiers were adjusted so that an amplitude of 500mV could be monitored on an oscilloscope. During the test the EMGs were expressed as a percentage of these reference values. Electromyography less than 10% of the reference activity were considered 0. The threshold of 10% agreed with accidental tension on the EMG-electrode cables or influences from shifting of the subject on the ISLR set-up.[3,11] Note that the reference levels as defined were not the maxima voluntary contraction (MVC) activity. Muscle activity could influence the measured lift force and the calculated muscle moment. The maximum passive muscle moment (stiffness) $M_{e\text{-}pas}$ was calculated at the onset of the I-EMG.[16]

With the subject supine on the ISLR table, the ankle was placed in the sling connected to the force transducer, and the hip and knee goniometers were applied. In the horizontal position, the goniometers were adjusted to 0. The subject was instructed to relax and neither to resist nor to support the SLR and to push the button when an unpleasant stretch in the dorsal part of the thigh off the knee or pain was experienced. The

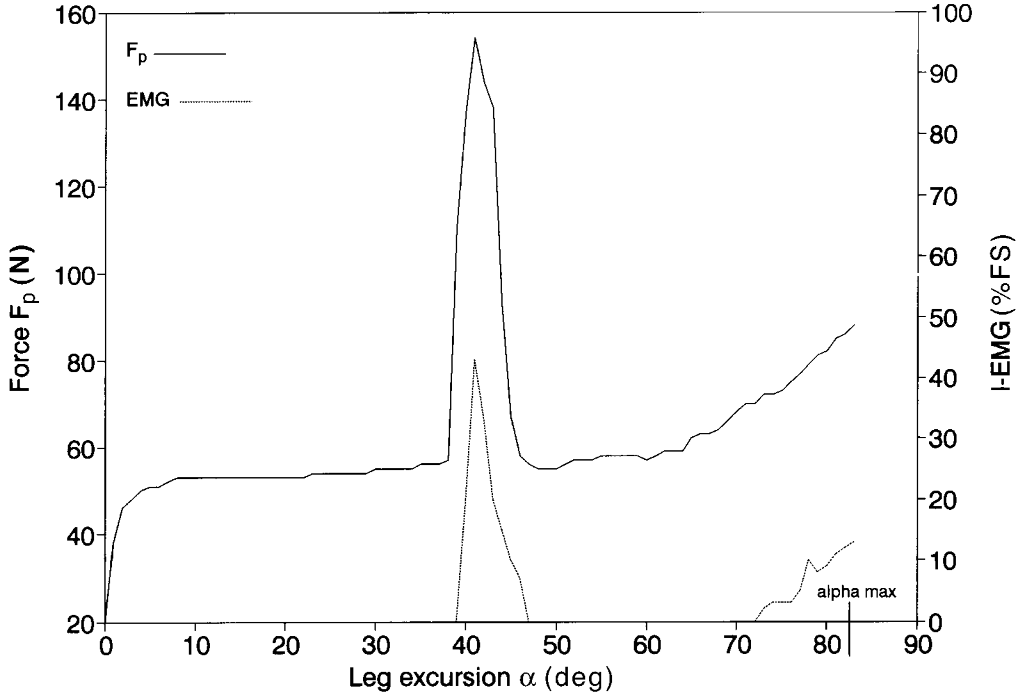

Fig 3. Force F_p and electromyographic activity of the semimembranosus as a function of angle α in a subject during ISLR. The subject was asked to contract and then to relax the hamstring muscles. ROM was defined by α_{max}. The pulling force F_p acts perpendicularly to the length axis of the leg at the ankle joint.

subject was also instructed to push the button and to say "stop" when no more tension or pain could be tolerated. At the maximum leg excursion, the maximum muscle moment (stiffness) $M_{e\text{-max}}$ was calculated. In the PG, the leg with the smallest excursion was measured, whereas in the control group the left leg was examined. The test was repeated 3 times with a 2-minute interval between each test. The first test was used to check for proper functioning of the equipment and for the subjects to get accustomed to the test. The second and third tests were used for data analysis. During the third test, halfway through the expected ROM, the subject was asked to resist the SLR by a submaximal contraction and then to relax. In this way both the level of the EMGs was measured and the active muscle moment $M_{e\text{-act}}$ (stiffness) was calculated. This measurement was introduced because it was expected that the active muscle stiffness was reduced because of the LBP. As an example, the total lift force F_p and the electromyographic activity of the semimembranosus as a function of the leg excursion are shown in figure 3. ROM was defined by the maximum leg excursion. No warm-up or stretching exercises were performed by the subjects before the test.

Data Processing

Analog signals from electrogoniometers, linear displacement potentiometers, force transducers, EMGs, and pain/stretch indicators were converted with a 12-bit A/D converter[g] at 100Hz and stored in a computer[h] for processing and analysis. ROM, pelvic-femoral angle, knee flexion, lordosis, lift force, and electromyographic activity of the hamstrings and back muscles were recorded during ISLR.

Based on the lift force data, the $M_{e\text{-max}}$, $M_{e\text{-act}}$, and $M_{e\text{-pas}}$ were calculated. Figure 4 shows the muscle stiffness M_e, the I-EMG of the hamstring muscles (semimembranosus), and the first sensation of pain as a function of the pelvic-femoral angle during the second test. For statistical analysis of the hamstring response during a maximum passive hip flexion test, the second and third tests were included. The significance of the differences of the mean values were determined with the Student's *t* test. Data were analyzed by using statistical software.[i] Statistical significance was set at alpha level of .05.

RESULTS

The descriptive statistics of the personal data and examined variables of the subjects of the 3 groups: FG, SG, and PG are presented in tables 1 and 2, respectively. Tables 3 and 4 list the significance of the mean differences of the ROM of the leg, pelvic-femoral angle, $M_{e\text{-max}}$, $M_{e\text{-pas}}$, $M_{e\text{-act}}$, onset of the I-EMG, first sensation of pain, lumbar lordosis, and pelvic tilt.

Personal Data

None of the subjects of the SG and PG could touch the ground with their fingers (finger-to-ground distance $>$ 0cm). All the subjects of the FG could touch the ground with their fingers (finger-to-ground distance $=$ 0cm). The finger-to-ground distance in the PG is greater than in the SG (table 1, $p <$ .05).

ROM and Extensibility

ROM and extensibility of the hamstrings are represented by the maximum lift angle and the pelvic-femoral angle, respectively. ROM and extensibility in the SG were significantly smaller compared with the FG (table 3). There was no significant difference in the extensibility of the back muscles ($p >$ .05). One man in the FG had a ROM greater than 90°. In his case, the variables were analyzed for angle $\alpha = 90°$. ROM and the hamstring extensibility in the PG were significantly smaller compared with the SG (table 4). There was no significant

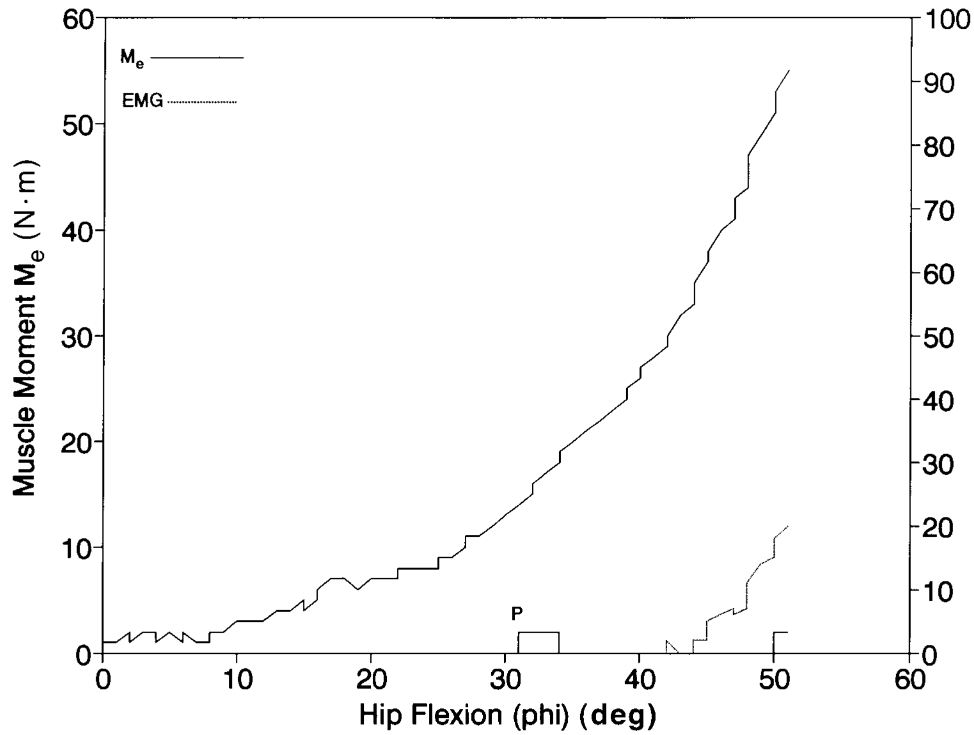

Fig 4. The muscle moment (stiffness) M_e, the electromyographic activity of the semimembranosus, and the first sensation (FS) of pain (P) as a function of the pelvic-femoral angle (ϕ) during ISLR.

difference in extensibility of the back muscles between the SG and PG ($p > .05$).

Muscle Stiffness

No significant differences in passive muscle stiffness (table 3) were found between the SG and FG ($p > .05$). There were no significant differences between $M_{e\text{-max}}$ and $M_{e\text{-act}}$ stiffness. The $M_{e\text{-max}}$ was calculated at the maximum lift angle. Comparison of the data of the SG and PG (table 4) showed no significant differences among $M_{e\text{-max}}$, $M_{e\text{-pas}}$, and $M_{e\text{-act}}$ stiffness ($p > .05$).

Table 2: Statistics for the FG, SG, and PG

Variable	FG (n = 8)	SG (n = 12)	PG (n = 20)
α_{max} (deg)*	84.4 ± 4.31	77.2 ± 7.47	66.5 ± 11.02
ϕ_{max} (deg)*	55.0 ± 5.40	48.2 ± 6.69	40.3 ± 10.41
$M_{e\text{-act}}$ (N · m)	66.5 ± 24.48	88.9 ± 35.99	91.4 ± 40.65
$M_{e\text{-max}}$ (N · m)	43.9 ± 12.02	49.7 ± 20.22	47.9 ± 27.22
$M_{e\text{-pas}}$ (N · m)	34.4 ± 13.04	38.0 ± 14.18	34.9 ± 22.11
ϕ_{EMG}* (deg)	48.1 ± 9.51	42.0 ± 8.70	26.8 ± 11.90
ϕ_P* (deg)	52.4 ± 7.16	42.2 ± 9.62	34.4 ± 11.86
h (mm)	20.4 ± 7.69	22.7 ± 7.59	23.1 ± 6.89
ψ_{max} (deg)	29.5 ± 7.13	29.2 ± 6.66	26.2 ± 6.35

NOTE. Data presented as mean ± SD.
Abbreviations: α_{max}, ROM; ϕ_{max}, pelvic-femoral angle; $M_{e\text{-act}}$, active muscle stiffness; $M_{e\text{-max}}$, maximum muscle stiffness; $M_{e\text{-pas}}$, passive muscle stiffness; ϕ_{EMG}, onset of EMG of the hamstrings; ϕ_P, first sensation of pain; h, maximum lumbar lordosis; ψ_{max}, pelvic tilt.
* $p < .05$.

Electromyograms

There was no significant difference in the onset of the I-EMG for the subjects of the SG and FG ($p > .05$) (table 3). The onset of the I-EMG for the subjects of the PG was significantly earlier than the subjects of the SG ($p < .05$) (table 4). The onset of I-EMG concerned the muscle activity of the hamstring muscles. In 14 subjects of the PG and 2 subjects of the SG, there was also electromyographic activity in the back muscles during SLR. The subjects of the FG did not show any electromyographic activity of the back muscles.

Pain Sensation

Comparison of the SG and FG (table 3) showed that the first sensation of pain for the SG was significantly earlier ($p < .05$). There were no significant differences between the subjects of

Table 3: Results of the 2-Tailed Independent Samples *t* Test for FG and SG

Variable	Mean Difference	SD Difference	Sign t
α_{max} (deg)	–7.1	2.93	.026*
ϕ_{max} (deg)	–6.8	2.84	.027*
$M_{e\text{-act}}$ (N · m)	+22.4	14.61	.142
$M_{e\text{-max}}$ (N · m)	+5.9	7.98	.471
$M_{e\text{-pas}}$ (N · m)	+3.6	6.27	.571
ϕ_{EMG} (deg)	–6.1	4.57	.200
ϕ_P (deg)	–10.2	4.20	.027*
h (mm)	+2.4	3.48	.504
ψ_{max} (deg)	–0.33	3.12	.916

NOTE. + or − indicates increase/decrease of the variables of the SG compared with the FG.
*$p < .05$, significant.

Table 4: Results of the 2-Tailed Independent Samples *t* Test for SG and PG

Variable	Mean Difference	SD Difference	Sign *t*
α_{max} (deg)	−10.7	3.60	.006*
ϕ_{max} (deg)	−7.8	3.37	.027*
$M_{e\text{-}act}$ (N · m)	+2.5	14.24	.863
$M_{e\text{-}max}$ (N · m)	−1.8	9.09	.844
$M_{e\text{-}pas}$ (N · m)	−3.1	7.15	.668
$\phi_{EMG\ (deg)}$	−15.2	4.71	.004*
ϕ_p (deg)	−7.8	4.05	.064
h (mm)	+0.3	2.61	.894
ψ_{max} (deg)	−2.9	2.36	.218

NOTE. + or − indicates increase/decrease of the variables of the PG compared with the SG.
* $p < .05$, significant.

the SG and PG ($p > .05$) (table 4). Two patients of the PG indicated a first sensation of pain almost in the beginning of the SLR. Their pain scores were not analyzed.

Lumbar Lordosis

The lordosis was not significantly different between the subjects of the SG and FG, or between the subjects of the SG and PG ($p > .05$) (tables 3, 4). In 8 of 20 subjects in the PG, the lordosis had decreased to 0 (back flat) by the end of the leg raise. In SG, 8 of 12 subjects in the SG, the lordosis had decreased to 0. In all subjects of the FG, the lordosis reached 0 during SLR.

DISCUSSION

The study results showed a smaller ROM of the SG versus the FG and a smaller ROM of the PG versus the SG. ROM in the PG was the smallest of the 3 groups, and consisted of the contribution of the extensibility of the hamstrings and back muscles. The small ROM in both the SG and PG can be explained by the small extensibility of the hamstrings. There were no differences in extensibility of the back muscles. Therefore, the inability to touch the ground in a forward bending test in the SG and PG was mainly explained by the limited extensibility of the hamstrings. We concluded that in the PG the small ROM was not accompanied by a decreased pelvic tilt or mobility of the low back. Leg excursion as a result of the elongation of the muscles could be accompanied by muscle activation.[14] In our study, we recorded electromyographic activity of the hamstrings and back muscles during the SLR. The onset of the I-EMG of the hamstrings was close to the maximum leg excursion in the subjects of the FG and SG. The I-EMG gradually increased with the leg raise and reached its maximum value at the maximum leg excursion. This is a normal defense reaction and in line with previous work in our laboratory.[14] There was no significant difference in the onset of the I-EMG of the hamstrings between the FG and SG.

The onset of the I-EMG of the hamstrings in the PG was significantly earlier compared with the SG. In 14 PG subjects and 2 SG subjects, there was also early electromyographic activity present in the gluteus maximus or erector spinae. In that sense, the electromyographic pattern differed from the normal defense reaction. However, the electromyographic pattern also did not agree with an abnormal defense reaction. The activity was not simultaneous in all the muscles and there was no fast increase in activity. In the FG, there was no significant electromyographic activity in the gluteus maximus and erector spinae (EMGs < 10% of the reference activity).

There was a significant difference in the first sensation of pain between the FG and SG, with the latter indicating pain much earlier. In previous work, the general experience was that subjects indicated, first, sensations of pain and then to stop the movement (ie, the elongation of the hamstrings).[3,4,13] The individual first sensation of pain was mostly described as an unpleasant feeling of tension in the dorsal part of the thigh off the knee (fossa poplitea) arising during the leg raise. At the stop of the leg raise, the subject could not tolerate more painful tension.

The early presence of electromyographic activity in erector spinae or gluteus maximus in the PG was not accompanied by an earlier first sensation of pain. There were no significant differences for the first sensation of pain between the SG and PG. The early presence of electromyographic activity in erector spinae or gluteus maximus and the shift of electromyographic activity of the hamstrings in the PG might be attributed to arousal. When the patient is exposed to feared stimuli, the EMG of the lumbar muscles will increase.[17] For instance, the patient expects the movement to be painful and reacts with a enhanced sensitivity of the muscle-tendon system subjected to stretch. At the same time, irritability of the sciatic nerve is not excluded. The onset of I-EMG and first sensation of pain were coupled in the subjects of the SG (table 2). In the PG, the difference had increased: 2 patients indicated a first sensation of pain at the start of the leg raise. It is unclear if they really perceived pain because of the movement or if they anticipated possible pain. It was, however, no reason for them to stop the leg raise.

During the third test, the subjects and patients were asked to resist (submaximal) the leg raise for a few seconds and then to relax (fig 3). The idea was that, in patients with LBP, active resistance was reduced because of LBP. The PG, however, showed no significant difference in the active muscle stiffness with respect to the SG. The active muscle stiffness for each subject of the PG was significantly higher than the $M_{e\text{-}max}$ at the end of the leg raise. The same applies to the FG and SG. The level of the I-EMG during the submaximal contraction was higher than the level at the end of the leg raise (fig 3). In addition, the measured EMG to resist the movement of the leg was less than the MVC. The presence of LBP did not influence the active muscle stiffness. We concluded that the ability to generate muscle force was not affected by LBP.

Subjects with limited ROM and patients with LBP have been said to react stiffly and the limitation on ROM is usually attributed to an insufficient elasticity or increased stiffness of the muscles.[11] Hamstring muscle is a composite of several anatomic elements: outer connective tissue sheath (epimysium), perimysium, and endomysium, sarcolemma, individual fiber contents, proximal and distal tendons, and adhesions to neighboring structures. The various elements probably have different length-tension characteristics. The muscle stiffness for the passive muscle is, therefore, formed by contributions from each of its elements.[18-20] In our study, there were small interindividual differences in hamstring muscle stiffness.

However, the passive muscle moments of the SG and PG did not differ. Note that equal passive muscle stiffness occurred at different angles of elongation of the hamstrings (ϕ_{EMG} in table 2). It might be concluded that the PG had a higher passive hamstring muscle stiffness. This finding does not agree with other studies, in which no differences were found in muscle stiffness. Because no differences were found between the short hamstrings group and a comparable normal control group, it is unlikely that these patients with LBP should have increased muscle stiffness. One explanation for this discrepancy is the definition of the onset of the EMG of the hamstring muscles.

EMGs less than 10% of the reference activity were considered 0. However, the beginning of electric activity, mostly in the semimembranosus, does not mean that the hamstring muscles are passive before that specific moment. Muscular activity less than 10% probably could have influenced the passive muscle stiffness in the patients.

The limited ROM and extensibility of the hamstrings in the patients was not accompanied by increased stiffness of the hamstrings. We concluded that the decreased extensibility and not the muscle stiffness was the limiting factor in SLR in patients with NSLBP. The stretch tolerance of the patient determines the extensibility. The maximum lumbar lordosis, measured when the subject was supine, was not significantly different between the SG and FG or between the SG and PG. A diminished lumbar lordosis in patients with LBP might have correlated with a diminished extensibility of the back muscles. But, this was not the case. During SLR, the flattening of the lumbar lordosis caused by the pelvic tilt was measured. In 12 subjects of the PG, the lordosis did not decrease to 0 (back flat on the table) at the end of the leg raise. Because the stop criterion was a painful feeling of tension in the dorsal part of the thigh off the fossa poplitea, a complete decrease of the lordosis (flat back) was not ruled out when further leg raise was possible. In addition, in 14 subjects of the PG, there was electromyographic activity present in the gluteus maximus or erector spinae. In the SG, in 4 subjects the lordosis did not decrease to 0. In 2 subjects of the SG, there was electromyographic activity present in the gluteus maximus or erector spinae during the leg raise. Decreased flattening of the lumbar lordosis was accompanied by electromyographic activity of the back muscles. However, there was no significant decreased extensibility of the back muscles. In all the subjects of the FG, the lordosis reached 0 and there was no electromyographic activity in the back muscles.

CONCLUSION

This study sought to analyze the role of the hamstring muscles in NSLBP patients with a limited SLR. It may be concluded that the inability to touch the ground and a limited SLR mainly was caused by a limited extensibility of the hamstrings. This limited extensibility was not caused by increased muscle stiffness. The muscle stiffness in the PG did not differ from subjects of the SG. Therefore, we concluded that the stretch tolerance of the patients was the limiting factor in SLR. The extensibility of the back muscles and through that the pelvic tilt did not differ between the PG and SG. The elongation of the back muscles in the PG was accompanied by electromyographic activity, possibly caused by arousal. A normal defense reaction of the hamstrings was present in the subjects of the SG and PG. In addition, there was low muscle activity in the back muscles during SLR. The early onset of muscle activity of the hamstrings in the patients as well as the presence in the gluteus maximus and erector spinae was probably caused by factors outside the muscles, like arousal. It was hypothesized that in patients with NSLBP, stretching exercises only could be applied when the hamstrings showed similar behavior, as in subjects with short hamstrings. Because the movement restriction was not caused by high muscle stiffness or by the electromyographic activity of the back muscles, stretching exercises to increase ROM were not indicated. Stretching exercises will only influence ROM by increasing the extensibility of the hamstrings.[4,5] Another argument to reject stretching exercises is the possible role of the ischiadic nerve or roots in patients with LBP. Relaxation exercises to reduce the presence of electromyographic activity in hamstrings and back muscles might be recommended.

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