Influence of Posture and Muscle Length on Stretch Reflex Activity in Poststroke Patients With Spasticity

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Objective: To investigate the influence of different positions on stretch reflex activity of knee flexors and extensors measured by electromyography in poststroke patients with spasticity and its expression in the Ashworth Scale.

Design: Crossover trial with randomized order of positioning.

Setting: Outpatient rehabilitation center in the Netherlands.

Participants: Poststroke patients (N=19) with lower-limb spasticity.

Intervention: Changing position: sitting versus supine.

Main Outcome Measures: Root mean square (RMS) values of muscle activity and goniometric parameters, obtained during the pendulum test and passive knee flexion and extension, and Ashworth scores.

Results: RMS values of bursts of rectus femoris activity were significantly higher in the supine compared with the sitting position (P=.006). The first burst of vastus lateralis activity during the pendulum test (P=.049) and semitendinosus activity during passive stretch (P=.017) were both significantly higher in the supine versus the sitting position. For both the pendulum test and passive movement test, the duration and amplitude of the cyclic movement of the lower leg changed significantly as well. In the supine position, we found significantly higher Ashworth scores for the extensors (P=.001) and lower scores for the flexors (P=.002).

Conclusions: The outcome of clinical and neurophysiologic assessment of spasticity is influenced considerably by subject positioning.

Key Words: Muscle spasticity; Posture; Rehabilitation; Stroke.

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SPASTICITY OCCURS IN 38% TO 60% OF PATIENTS SURVIVING 12 MONTHS AFTER STROKE,1 ALTHOUGH PREVALENCE FIGURES VARY BETWEEN STUDIES.2,3 FUNCTIONALLY, PATIENTS WITH SPASTICITY ARE SIGNIFICANTLY MORE IMPAIRED THAN PATIENTS WITHOUT SPASTICITY.1

LANCE4 DEFINED SPASTICITY AS A MOTOR DISORDER CHARACTERIZED BY A VELOCITY-DEPENDENT INCREASE IN MUSCLE TONE IN RESPONSE TO STRETCHING RELAXED MUSCLE. RECENTLY, THE SUPPORT PROGRAMME FOR ASSEMBLY OF DATABASE FOR SPASTICITY MEASUREMENT PROJECT REDEFINED SPASTICITY AS “DISORDERED SENSOMOTOR CONTROL, RESULTING FROM AN UPPER MOTOR NEURONE LESION, PRESENTING AS INTERMITTENT OR SUSTAINED INVOLUNTARY ACTIVATION OF MUSCLES.”5 6 7 8 THIS DEFINITION INCLUDES ALL THE POSITIVE FEATURES OF THE UPPER MOTORNEURON (UMN) SYNDROME BUT EXCLUDES THE NEGATIVE FEATURES AND THE BIOMECHANIC CHANGES IN THE JOINTS AND SOFT TISSUES.

OBJECTIVE MEASUREMENT IS RELEVANT FOR THE INDICATION FOR AND EVALUATION OF TREATMENT OF SPASTICITY. IN CLINICAL SITUATIONS, HOWEVER, THE ASSESSMENT IS VERY POORLY STANDARDIZED, AND THEREFORE ITS VALUE FOR FINE-TUNING AN INTERVENTION IS LIMITED. THE ASHWORTH SCALE, IN TERMS OF ASSESSMENT OF RESISTANCE TO PASSIVE MOVEMENT, IS THE MOST COMMON CLINICAL MEASURE FOR SPASTICITY. THE LIMITED RESEARCH CONCERNING CLINIMETRIC PROPERTIES OF THIS SCALE SHOWS THAT INTRARATER AND INTERRATER RELIABILITY AS WELL AS TEST-RETEST RELIABILITY ARE MODERATE.6,8 A LACK OF STANDARDIZATION DURING SCORING MIGHT HAVE CONTRIBUTED TO THESE RESULTS. IN THE ORIGINAL DESCRIPTION OF THE ASHWORTH SCALE,9 INSTRUCTION FOR PATIENT POSITIONING IS NOT INCLUDED. IN PRACTICE, CLINICIANS USUALLY KEEP PATIENTS LYING ON A BED OR SITTING IN A WHEELCHAIR FOR PRACTICAL REASONS.

BECAUSE SPASTICITY IS KNOWN TO BE LENGTH DEPENDENT, THE POSITIONING OF SUBJECTS DURING TESTING IS LIKELY TO INFLUENCE THE RESULTS OF THE SPASTICITY ASSESSMENT, PARTICULARLY WHEN BI-ARTICULAR MUSCLES ARE INVOLVED. DIFFERENT RESEARCHERS10-14 HAVE STATED THAT IN LARGER MUSCLE GROUPS INCREASING LENGTH OF THE MUSCLE AUGMENTS THE STRETCH REFLEX ACTIVITY. HOWEVER, IN THE CASE OF QUADRICEPS MUSCLE, A STUDY BY BURKE ET AL13 SHOWED THAT MUSCLE LENGTHENING SEEMS TO HAVE AN INHIBITORY EFFECT.

IN THE TRIALS REPORTED IN THE LITERATURE,13,14,16 SUBJECTS’ POSITIONS VARY GREATLY DURING THE PENDULUM TEST AND PASSIVE MOVEMENT TESTS OF THE LOWER EXTREMITIES, WITH SOME Undertaking THE TESTS WITH SUBJECTS SUPINE AND OTHERS HAVING SUBJECTS SITTING UPRIGHT OR IN INTERMEDIATE POSITIONS.

ONLY A FEW ARTICLES COMPARE FINDINGS IN 2 POSITIONS. VODOVNIK ET AL18 FOUND THAT IN HEMIPARETIC PATIENTS A CHANGE IN BODY POSITION FROM SITTING TO SUPINE INCREASED THE SPASTIC STATE DURING THE PENDULUM TEST, WITH MORE ELECTROMYOGRAPHIC ACTIVITY IN THE QUADRICEPS AND CHANGES IN THE GONIOMETER. HE19 DESCRIBED SIMILAR FINDINGS IN 59 PATIENTS WITH MULTIPLE SCLEROSIS (MS). KAKEBEEKE ET AL20 COMPARED THE ELICITED TORQUES IN THE HAMSTRING AND QUADRICEPS MUSCLES IN THE SUPINE AND SITTING POSITIONS DURING PASSIVE MOVEMENT IN 20 PATIENTS WITH SPINAL CORD INJURY WITH A COMPLETE MOTOR LESION. FOR BOTH KNEE FLEXORS AND EXTENDORS THE TORQUE WAS HIGHER IN THE LENGTHENED COMPARED WITH THE MORE SHORTEST MUSCLES.

STUDIES21,22 INVOLVING THE ANKLE AND UPPER-LIMB MUSCLES HAVE SHOWN SIMILAR DEPENDENCE OF REPLY RESPONSE ON JOINT POSITION AND MUSCLE LENGTH. EVEN IN PEOPLE WITHOUT NEUROLOGIC DISORDER, MUSCLE LENGTHENING HAS LED TO AN INCREASED REFLEX RESPONSE IN THE PREACTIVATED GASTROCNEMIUS23-25 POSSIBLY BECAUSE OF CHANGES IN INTRINSIC MUSCLE CHARACTERISTICS.

THE CONTRADICTING FINDINGS IN THE LITERATURE ABOUT THE INFLUENCE OF MUSCLE LENGTH ON STRETCH REFLEX ACTIVITY, ESPECIALLY IN THE QUADRICEPS MUSCLE, RAISE 2 QUESTIONS. THE FIRST IS WHETHER AND HOW THE STRETCH REFLEX IN THE QUADRICEPS AND HAMSTRING...
randomization was performed mainly because of the occurrence which the order of positioning was randomized for all patients. The aim of this study was to investigate the influence of the change in positioning on stretch reflex activity of the rectus femoris, vastus lateralis, and semitendinosus muscles on the affected and nonaffected sides as measured by surface electromyography. A second aim was to assess whether the possible variability in stretch reflex activity in different positions is also expressed by a change in Ashworth scores.

We hypothesized that the stretch reflex of the rectus femoris would be elicited more strongly in the supine position, when the muscle is elongated, compared with the sitting position. For the semitendinosus muscle, we expected the opposite: that is, more stretch reflex activity in the sitting position. The stretch reflex of the vastus lateralis was not expected to be influenced by changing the hip angle, because the length of this monarticular muscle does not change. Finally, we expected that possible differences in electromyographic activity in the 2 positions during passive movement would not (or not to the same extent) be discriminated by the Ashworth Scale.

METHODS

This explorative study was a crossover randomized trial in which the order of positioning was randomized for all patients. Randomization was performed mainly because of the occurrence of fatigue in repeated stretching of a spastic muscle.26,27

The study received ethics approval from the medical ethics committee of Rehabilitation Centre Het Roessingh in Enschede, the Netherlands.

Study Population

Patients with spasticity in the lower limb after a unilateral cerebrovascular accident were included if they were at least 6 months poststroke. In addition, they had to be able to move the lower leg against gravity and understand simple commands. Patients were excluded if full hip or knee extension was not possible, if they had pain or other complaints in the lower limbs, or a history of surgery on the lower limbs.

Procedure

Stretch reflex activity was studied clinically by the Ashworth Scale and neurophysiologically during the pendulum test and passive movement of the lower leg. All 3 tests were performed in the supine and sitting positions, in random order. We divided the study population into 2 groups (A, supine-sitting; B, sitting-supine). Block randomization was performed by tossing a coin.

We chose for a fixed order of tests, starting on the unaffected side, to enable patients to get used to the movements and the demanded tasks (appendix 1). Before performing the tests each test was explained and tried once.

Measurements were always performed by the same examiners. Initially the passive range of motion (ROM) of both hips and knees was assessed, as was muscle length (slow Duncan-Ely test for the rectus femoris, popliteal angle for the hamstrings), to ensure that no structural contractures would interfere with the test results.

In the supine position, each subject laid on the bed with a small pillow under the head and, if necessary, support under the back. The lower legs were hanging over the edge and could move freely. In the sitting position, each subject was in a comfortable upright position with the hips ±90° flexed and with support for the back and lumbar region.

The Ashworth score was assessed by an experienced physiotherapist, blinded to the objective of the study or test results. The score was assessed for both knee flexors and extensors in the 2 described subject positions. No other instructions were given so as not to influence the therapist and thereby to approximate a typical clinical situation as much as possible.

Neurophysiologic measurements consisted of the pendulum test and the passive movement test. For the pendulum test, the lower leg of each subject was held in full knee extension and released. During the passive movement test the lower leg of each subject was moved 10 times by the investigator, alternating from full extension to 90° of knee flexion. The lower leg was rotated in a steady regular way at a pace that was least laborious for the investigator, which is similar to pendulum or resonant frequency. Each subject had been instructed to relax his/her leg and not to oppose or facilitate the movement of the swinging leg during these measurements. The pendulum and passive movement tests all were performed 3 times.

Instrumentation

The knee joint angle was measured with a biaxial electric goniometer, placed on the lateral side of the knee. Surface electromyographic signals were obtained from the rectus femoris, vastus lateralis, and semitendinosus muscles, using electrode placement procedures according to the Surface EMG for Non-Invasive Assessment of Muscles—based protocol.28 Bipolar, pregelled circular (diameter, 10mm; solid gel) electrodes were used with an interelectrode distance of 24mm. A reference electrode was placed around the wrist.

Electromyographic data were amplified, band-pass filtered (third-order Butterworth; cutoff frequencies, 20Hz, 500Hz), and sampled at 1000Hz (12-bit analog to digital). The goniometer signal was low-pass filtered with a cutoff frequency of 10Hz. We used software specifically developed for analysis of muscle activation patterns during the pendulum test and passive movement. Knee angle and surface electromyographic signals were synchronized. Raw electromyographic data were transformed to values of root mean square (RMS), related to the different phases (knee flexion, knee extension) of each cycle. In addition, an algorithm (the approximated generalized likelihood ratio) was used to determine the start and end of bursts in the electromyographic signals.

Outcome Parameters

We used 2 groups of parameters to get insight in the movement and muscle activation patterns.

The parameters describing the movement were derived from the goniometric signal and divided the cycle into a flexion and extension phase. The duration reflects the time necessary for knee flexion (first half of the cycle) and knee extension (second half of the cycle). The amplitude of the cycle represents the ROM during the tests. These parameters are primarily relevant for the pendulum test, because changes in these parameters indicate a different degree of resistance against movement. For the passive movement test they are merely a verification of how accurately the test has been performed.

In the pendulum test the duration and amplitude of the first flexion phase decrease when more spasticity in the knee extensors is present.30 The relaxation index is a frequently used ratio for the pendulum test, derived from the knee angle. It is defined as the ratio between the angle of the first drop and the initial angle (with the resting angle as 0°).30 In healthy subjects, the relaxation index is found to be 1.6 or more. Lower scores represent spasticity.
We used RMS values derived from electromyographic signals to describe muscle activation patterns. This is a measure of the amount of muscle activity during a period of time (e.g., flexion phase, extension phase, during a burst of muscle activity).

The parameters for the pendulum test all were based on the first cycle (figs 1, 2): the duration of the first knee flexion ($D_{\text{flex}}$) and extension movement ($D_{\text{ext}}$), cycle amplitude of flexion ($A_{\text{flex}}$) and extension ($A_{\text{ext}}$), and the relaxation index. Furthermore, for each muscle RMS during flexion ($\text{RMS}_{\text{flex}}$) and extension ($\text{RMS}_{\text{ext}}$) were assessed, as was RMS of the first burst, if present ($\text{RMS}_{\text{burst}}$).

For the passive movement test, similar parameters were used as for the pendulum test, but averages of 10 cycles were calculated: average duration of knee flexion and extension, average cycle amplitude of flexion and extension, average RMS during knee flexion and extension, and average RMS during burst activity, if present, for each muscle.

The parameters for muscle activity during knee flexion and knee extension have different significance for the antagonizing muscles: during knee flexion, the rectus femoris elongates and might show stretch reflex activity, but no voluntary activity (besides cocontraction or when a subject is unable to relax).

During knee extension, the rectus femoris shortens; we do not expect stretch reflex activity here, so the muscle activity we find in this phase is defined as active muscle contraction. For the semitendinous muscle, the opposite is assumed.

The Ashworth Scale was scored according to the original scale (range, 0–4).9

**Statistical Analysis**

The data were analyzed using Statistical Package for Social Sciences (SPSS) for Windows. We compared data from the sitting position with that from the supine position using the paired $t$ test or Wilcoxon signed-rank test (depending on the distribution of the differences) with a significance level of .05. For the pendulum and passive movement test the means of 3 measurements were used for each subject.

To provide criteria for what might be normative changes not directly related to pathologic muscle activation, we also measured the unaffected side. To investigate the importance of the differences found on the affected leg, we compared these outcomes with the results on the unaffected side. We used a linear mixed model with 2 factors (position, affected and nonaffected side) to compare the effect of position change for the affected and unaffected sides. To determine whether an interaction between position and order of positioning (carryover effect) was present, a 3-factor analysis was performed with the group (A, B) as the third factor.

Furthermore, we calculated correlations between the Ashworth score and electromyographic parameters of knee flexor and extensor muscles with the Spearman correlation coefficient. We compared the Ashworth scores for flexors and extensors with RMS values of these muscles during stretching and during a burst of activity, in both positions.

**RESULTS**

Twenty patients were recruited from the outpatient Department of Rehabilitation Medicine. All patients were informed about the purpose of the study and gave informed consent. The
results of 1 subject in group A were excluded for further analysis, because the subject appeared unable to relax during all the measurements.

Table 1 summarizes the baseline characteristics of groups A and B. The difference in mean age between the 2 groups was significant (Mann-Whitney U test, P=.04).

Table 1: Group Characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Group A (Supine-Sitting)</th>
<th>Group B (Sitting-Supine)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Mean age ± SD (y)</td>
<td>51.4±12.4</td>
<td>63.4±9.6</td>
</tr>
<tr>
<td>Women (%)</td>
<td>33.3</td>
<td>10.0</td>
</tr>
<tr>
<td>Right hemiparesis (%)</td>
<td>33.3</td>
<td>30.0</td>
</tr>
<tr>
<td>Nonhemorrhagic (%)</td>
<td>77.8</td>
<td>80.0</td>
</tr>
<tr>
<td>Mean months poststroke ± SD</td>
<td>38.9±46.7</td>
<td>27.1±24.5</td>
</tr>
</tbody>
</table>

Abbreviation: SD, standard deviation.

Table 2: Means of the Parameters of the Pendulum Test on the Affected Side in 2 Positions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sitting</th>
<th>Supine</th>
<th>Mean Difference (95% CI)*</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dmax (ms)</td>
<td>737.4</td>
<td>611.8</td>
<td>125.6 (69.9 to 181.3)</td>
<td>.001</td>
</tr>
<tr>
<td>Dext (ms)</td>
<td>453.4</td>
<td>387.7</td>
<td>65.7 (24.3 to 107.1)</td>
<td>.004</td>
</tr>
<tr>
<td>Amax (deg)</td>
<td>69.8</td>
<td>57.7</td>
<td>12.1 (6.9 to 17.2)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Aext (deg)</td>
<td>38.0</td>
<td>31.0</td>
<td>7.1 (0.9 to 13.2)</td>
<td>.026</td>
</tr>
<tr>
<td>Relaxation index</td>
<td>1.7</td>
<td>1.4</td>
<td>0.3 (0.1 to 0.4)</td>
<td>.001</td>
</tr>
<tr>
<td>RMS(RF)max (μV)</td>
<td>16.7</td>
<td>18.3</td>
<td>-1.7 (-4.0 to 0.6)</td>
<td>.145</td>
</tr>
<tr>
<td>RMS(RF)ext (μV)</td>
<td>3.9</td>
<td>5.9</td>
<td>-1.9 (-4.5 to 0.6)</td>
<td>.094</td>
</tr>
<tr>
<td>RMS(RF)burst (μV)</td>
<td>25.8</td>
<td>30.6</td>
<td>-4.8 (-7.9 to -1.6)</td>
<td>.006</td>
</tr>
<tr>
<td>RMS(VL)max (μV)</td>
<td>9.3</td>
<td>11.2</td>
<td>-1.8 (-4.9 to 1.3)</td>
<td>.229</td>
</tr>
<tr>
<td>RMS(VL)ext (μV)</td>
<td>2.9</td>
<td>4.0</td>
<td>-1.1 (-3.1 to 0.9)</td>
<td>.252</td>
</tr>
<tr>
<td>RMS(VL)burst (μV)</td>
<td>15.8</td>
<td>21.6</td>
<td>-5.8 (-11.6 to -0.04)</td>
<td>.048</td>
</tr>
<tr>
<td>RMS(ST)max (μV)</td>
<td>6.3</td>
<td>4.9</td>
<td>1.3 (-0.7 to 3.4)</td>
<td>.189</td>
</tr>
<tr>
<td>RMS(ST)ext (μV)</td>
<td>7.1</td>
<td>5.1</td>
<td>2.0 (-2.0 to 6.0)</td>
<td>.296</td>
</tr>
<tr>
<td>RMS(ST)burst (μV)</td>
<td>16.1</td>
<td>13.8</td>
<td>2.2 (-10.0 to 14.5)</td>
<td>.670</td>
</tr>
</tbody>
</table>

NOTE. P values are tested parametrically, unless mentioned.
Abbreviations: A, amplitude of movement; burst, during burst activity; CI, confidence interval; D, duration; ext, extension; flex, flexion; RF, rectus femoris; ST, semitendinosus; VL, vastus lateralis.

Although the RMS of the burst in the semitendinosus was higher in the sitting position compared with the supine, this difference was not statistically significant (P=.670).

Table 3 summarizes comparisons of the affected with the unaffected side. The differences in the parameters derived from the pendulum test, due to change of position, are presented for both the affected and unaffected sides. The P values indicate whether the effect of changing position differs for the affected compared with the unaffected side. Only parameters that show statistically significant differences between the sitting and supine positions on the affected side (see table 2) are presented. It is necessary to mention that we found an interaction between the order of positioning and the effect of position (carryover effect) for the parameters of cycle amplitude Aext (P=.016) and Aext (P=.010). When we analyzed the groups separately for these 2 parameters, the effect of changing position on cycle amplitude was stronger in group A (supine-sitting) than in group B (sitting-supine). For clarity of presentation we have used the combined figures.

From table 3, it can be derived that the change of the duration of the first knee flexion movement (Dmax), due to changing position, was significantly larger on the affected side (P=.002) compared with the unaffected side. The change of duration of extension (Dext) did not differ significantly, although the observed mean difference was larger on the affected side (65.7ms) than the unaffected side (10.9ms) (P=.056).

The amplitude of the movement differed more on the affected side for knee flexion (P=.042) but not for extension (P=.187). The changes in the relaxation index differed significantly between the affected and unaffected sides (P=.005).

On the affected side, the RMS values of the first burst in the rectus femoris and vastus lateralis increased significantly in the supine position (see table 2). Compared with the unaffected side, however, these changes do not seem important.

Passive Movement Test

When comparing the parameters of the passive movement test between the 2 positions, we found that the duration of extension and amplitude of the movement changed significantly (table 4). The difference between duration of flexion in
the sitting versus the supine position was not significant at the 5% level.

Rectus femoris activity was generally higher in the supine position, during knee flexion as well as during extension, although these differences were not statistically significant. The burst activity was significantly higher throughout the supine position (mean difference RMS, $-4.0\mu V$; $P=.007$). For the vastus lateralis, all observed values were higher in the supine compared with the sitting position, but the differences were not statistically significant. The RMS of the semitendinosus during extension was higher in the sitting position (mean difference, 6.6$\mu V$; $P=.017$).

For the passive movement test, the same type of comparison between the affected and unaffected sides was performed. Table 5 shows the results of this analysis. On the affected side, the duration of knee extension and the amplitude of the movement changed significantly with changing position on the affected side. On the unaffected side, however, these parameters changed as well ($P=.008$ for duration; $P=.017$ for amplitude of flexion; $P=.006$ for amplitude of extension). The changes were comparable on both sides (all $P>.05$). Similarly, the changes in RMS of rectus femoris burst activity and the change of RMS of the semitendinosus during extension could not be discriminated.

Ashworth Scale

In the supine position, we found significantly higher Ashworth scores for the knee extensors (Wilcoxon signed-rank test, $P=.001$) and lower scores for the knee flexors ($P=.002$). Table 6 shows the shift to lower scores for the extensors in the sitting position and for the flexors in the supine position. On the unaffected side, all scores for flexors and extensors were zero (no increase in tone) in both positions.

The correlation coefficients between the Ashworth scores for the extensors and the RMS values of the rectus femoris during stretch while performing the pendulum test were moderate in both the sitting and supine positions (table 7). All values were significant at the 5% level. For the passive movement test, however, the correlation coefficients were low, particularly in the sitting position, and most of them did not reach a level of significance. For the knee flexors, correlation coefficients were low and nonsignificant in both the sitting and supine positions.

**DISCUSSION**

The aim of this study was to investigate the influence of position on stretch reflex activity of knee flexor and extensor muscles in stroke subjects with known spasticity in the affected leg. In addition to what was done in earlier studies, we performed the Ashworth Scale in 2 positions and recorded surface electromyography during the pendulum test and passive movement of the limb.

The results of the neurophysiologic tests in this study confirm our hypothesis that a muscle in an elongated state shows more stretch reflex activity compared with a muscle in a shortened state. The findings of Burke et al about the inhibitory effect of quadriceps lengthening are therefore contra-

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sitting (ms)</th>
<th>Supine (ms)</th>
<th>Mean Difference (95% CI)</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{max}$</td>
<td>703.6</td>
<td>760.3</td>
<td>$-56.7$ ($-109.7$ to $-3.6$)</td>
<td>.059*</td>
</tr>
<tr>
<td>$D_{mean}$</td>
<td>640.5</td>
<td>608.7</td>
<td>$31.8$ ($3.3$ to $60.3$)</td>
<td>.044*</td>
</tr>
<tr>
<td>$A_{max}$</td>
<td>76.0</td>
<td>70.1</td>
<td>$5.9$ ($1.7$ to $10.1$)</td>
<td>.008</td>
</tr>
<tr>
<td>$A_{mean}$</td>
<td>76.2</td>
<td>70.2</td>
<td>$6.0$ ($1.8$ to $10.2$)</td>
<td>.008</td>
</tr>
<tr>
<td>RMS(RF)$_{max}$ ($\mu V$)</td>
<td>12.8</td>
<td>15.9</td>
<td>$-3.1$ ($-7.3$ to $1.1$)</td>
<td>.243*</td>
</tr>
<tr>
<td>RMS(RF)$_{mean}$ ($\mu V$)</td>
<td>5.1</td>
<td>5.5</td>
<td>$-0.4$ ($-2.5$ to $1.7$)</td>
<td>.689</td>
</tr>
<tr>
<td>RMS(VL)$_{max}$ ($\mu V$)</td>
<td>16.3</td>
<td>21.6</td>
<td>$-5.3$ ($-9.6$ to $-1.1$)</td>
<td>.007*</td>
</tr>
<tr>
<td>RMS(VL)$_{mean}$ ($\mu V$)</td>
<td>5.5</td>
<td>7.7</td>
<td>$-2.2$ ($-5.1$ to $0.7$)</td>
<td>.472*</td>
</tr>
<tr>
<td>RMS(ST)$_{max}$ ($\mu V$)</td>
<td>3.6</td>
<td>3.7</td>
<td>$-0.2$ ($-1.5$ to $1.2$)</td>
<td>.616*</td>
</tr>
<tr>
<td>RMS(ST)$_{mean}$ ($\mu V$)</td>
<td>22.3</td>
<td>15.6</td>
<td>$6.6$ ($1.5$ to $11.7$)</td>
<td>.017*</td>
</tr>
</tbody>
</table>

*Wilcoxon signed-rank test.
dicted by the results of our study. The graphically presented results of Burke et al.\textsuperscript{13} show that, for a constant velocity of knee flexion, the stretch reflex of the quadriceps muscle diminishes in amplitude when the passively imposed stretching movement is started with the knee joint more flexed. Because the starting angle was not randomized in Burke’s\textsuperscript{13} experiment, fatigue might play a role in the extinguishing stretch reflex. Another explanation could be that a nonoptimal placement of the electrodes on the quadriceps muscle caused a high sensitivity of observed electromyographic amplitude on change of knee angle.\textsuperscript{28}

In our study, the significant increase in burst activity of the vastus lateralis in the supine position during the pendulum test is noteworthy, because we did not expect to find any relevant change in this monoarticular muscle. Crossstalk is not expected to play a role here, because crosstalk from the rectus femoris in surface electromyography of the vasti is usually not seen, but rather the reverse. It might be a result of coactivation of the quadriceps muscle group, due to common pathways in the reflex arc, although the rectus femoris has been shown to function independently of the vasti during gait.\textsuperscript{31} In addition, myofascial force transmission may contribute to this phenomenon. As shown by Huijing and Baan,\textsuperscript{32} part of the total muscle force is transmitted to extramuscular connective tissue of a compartment and to adjacent muscles, rather than being transmitted to the insertion of a muscle tendon. Related to this, it was shown that the relative position of a muscle, with respect to its surrounding structures, influences the proximodistal force distribution within the muscle itself.\textsuperscript{33}

He\textsuperscript{19} also performed the pendulum test under different postural conditions in 59 MS patients. He described that changes both in the rectus femoris and vastii (medial and lateral heads) are seen in some patients with moderate or severe spasticity but not in patients with very mild spasticity, as assessed with the Ashworth score. This difference between mildly and more severely affected patients is not observed in our data, possibly because of our limited sample size.

The changes in goniometric parameters of the pendulum test in the 2 positions are large and significantly higher compared with the unaffected side. The mean value of the relaxation index on the affected leg in the sitting position could even be considered as normal\textsuperscript{50}; the mean relaxation index in the supine position, however, represents spasticity. These changes in goniometric parameters could be a result of both change in stretch reflex activity and changes in biomechanic factors. These cannot accurately be differentiated in this study, although an attempt is made by comparing with the unaffected side. Fowler et al.\textsuperscript{24} evaluating poststroke subjects and healthy people, concluded that soft-tissue changes rather than hyperreflexia may explain the goniometric changes found in their study. From different studies it becomes clear that the role of changes in intrinsic muscle characteristics after a UMN lesion is very complex.\textsuperscript{2,21,34,35} Many researchers\textsuperscript{2,21,34,35} are now focusing on the changes in sarcomere length as a result of the UMN syndrome, which implicates an indirect effect on stretch reflex activity. The number of sarcomeres decreases\textsuperscript{2,36} and sarcomere length increases in spastic muscles. Spastic muscle cells appear to be significantly shorter and less elastic than normal muscle cells,\textsuperscript{57} implying an increased resistance to stretch.

In this study, stretch reflex activity has been shown to play a role in the changed goniogram after position change. Increased spindle sensitivity might be contributing as a direct result of muscle elongation or in combination with increased stiffness of the spastic muscle. A change in the biomechanic properties of other soft tissues in different positions probably is part of the cause as well.

These biomechanic changes well might explain the large differences in clinical assessment with the Ashworth Scale between the 2 positions. These differences are remarkable, because we did not expect to find important changes measured by this rather crude scale. The low to moderate correlations between the Ashworth scores and the electromyographic parameters for muscle activity further emphasize the limited validity of the Ashworth Scale as a measure for spasticity.

**Study Limitations**

There are some limitations in this study that need to be mentioned. First, differences between the baseline characteris-

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**Table 5: Means of Differences of the Passive Movement Test on Affected and Unaffected Sides, Compared by a 2-Factor Analysis of Variance**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$\Delta_A$ (95% CI)</th>
<th>$\Delta_{AA}$ (95% CI)</th>
<th>Interaction* ($P$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{ext}$ (ms)</td>
<td>31.8 (3.3 to 60.3)</td>
<td>19.1 (4.0 to 34.2)</td>
<td>.542\textsuperscript{†}</td>
</tr>
<tr>
<td>$A_{ext}$ (deg)</td>
<td>5.9 (1.7 to 10.1)</td>
<td>5.5 (1.1 to 9.8)</td>
<td>.906</td>
</tr>
<tr>
<td>$A_{ext}$ (deg)</td>
<td>6.0 (1.8 to 10.2)</td>
<td>5.6 (1.2 to 10.0)</td>
<td>.911</td>
</tr>
<tr>
<td>RMS(RF)burst ($\mu$V)</td>
<td>−5.3 (−9.6 to −1.1)</td>
<td>−2.9 (−6.5 to 0.6)</td>
<td>.688\textsuperscript{†}</td>
</tr>
<tr>
<td>RMS(ST)$\textsuperscript{ext}$ ($\mu$V)</td>
<td>6.6 (1.5 to 11.7)</td>
<td>−0.9 (−2.7 to 1.0)</td>
<td>.065\textsuperscript{†}</td>
</tr>
</tbody>
</table>

*Interaction between position and side (affected or nonaffected). Expresses whether the effect of changing position differs for the affected compared with the unaffected side.

†After log transformation of the data (the mean values presented are observed means).

**Table 6: Ashworth Scores for Knee Flexors and Extensors on the Affected Side in 2 Positions**

<table>
<thead>
<tr>
<th>Ashworth Scale</th>
<th>Extensors (N=19)</th>
<th>Flexors (N=19)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Supine</td>
<td>Sitting</td>
</tr>
<tr>
<td>0=no increase</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>1=slight increase</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>2=more marked increase</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>3=considerable increase</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4=passive movement impossible</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

NOTE. Values express the number of times a value is scored.

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**Table 7: Spearman Correlation Coefficients of Ashworth Scores and RMS Values of the Knee Extensors and Flexors in 2 Positions**

<table>
<thead>
<tr>
<th>RMS Values (RF)</th>
<th>Ashworth Score: Extensors</th>
<th>Sitting</th>
<th>Supine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pendulum test</td>
<td>RMS(RF)flex</td>
<td>.55*</td>
<td>.51*</td>
</tr>
<tr>
<td></td>
<td>RMS(RF)burst</td>
<td>.51*</td>
<td>.48*</td>
</tr>
<tr>
<td>Passive movement</td>
<td>RMS(RF)flex</td>
<td>.31</td>
<td>.51*</td>
</tr>
<tr>
<td></td>
<td>RMS(RF)burst</td>
<td>.35</td>
<td>.45</td>
</tr>
<tr>
<td>RMS Values (ST)</td>
<td>Ashworth Score: Flexors</td>
<td>Sitting</td>
<td>Supine</td>
</tr>
<tr>
<td>Pendulum test</td>
<td>RMS(ST)ext</td>
<td>.37</td>
<td>.14</td>
</tr>
<tr>
<td></td>
<td>RMS(ST)burst</td>
<td>.22</td>
<td>0.00</td>
</tr>
<tr>
<td>Passive movement</td>
<td>RMS(ST)ext</td>
<td>.38</td>
<td>.27</td>
</tr>
<tr>
<td></td>
<td>RMS(ST)burst</td>
<td>.24</td>
<td>.35</td>
</tr>
</tbody>
</table>

*P<.05.

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**APPENDIX 1: SUMMARY OF THE PROCEDURE IN EACH POSITION**

- Ashworth score of flexors and extensors on unaffected side
- Ashworth score of flexors and extensors on affected side
- Pendulum test (3 times) on unaffected side
- Passive movement test (3 times) on unaffected side
- Pendulum test (3 times) on affected side
- Passive movement test (3 times) on affected side

**References**


Suppliers
a. Biometrics electrogoniometers; Biometrics Ltd, Unit 25 Nine Mile Point Ind Est, Cwmfelinfach, Gwent NP11 7HZ, UK.
b. ARBO H93; Tyco Healthcare, PO Box 2205, 5300 CE Zaltbommel, the Netherlands.
c. KL-100; Kinesiologic Laboratories (K-Lab), Haarlem, the Netherlands.
d. Version 11.5; SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.