

# Effects of lifting the non-paretic foot on muscle activity during the semi-squat exercise in hemiplegic patients

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**Abstract.** [Purpose] This study compared the electromyographic activity of the quadriceps in hemiplegic patients during the downward, maintenance, and upward phases of squat exercises performed with the feet parallel and with the non-paretic foot lifted. [Subjects] A total of 17 hemiplegic patients (9 males and 8 females) volunteered for this study. [Methods] All subjects performed squat exercises with the knees flexed to 30° and with the feet parallel (shoulder-width apart) or with lifting of the non-paretic foot (normalized to 25% of the knee height). [Results] The activity of the rectus femoris, vastus medialis oblique, and vastus lateralis muscles was significantly higher during squat exercises performed with the non-paretic foot lifted than with the feet parallel to each other. The activity of all muscles during the maintenance phase of the exercises was greater than that during the downward and upward phases. [Conclusion] Lifting the non-paretic foot during squats may represent an effective exercise for motor function rehabilitation in hemiplegic patients.

**Key words:** EMG, Foot lifting, Squat exercise

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## INTRODUCTION

Strengthening of the lower limbs is an important component of stroke rehabilitation and is associated with increased patient independence. Weight-bearing exercises, particularly double-legged squats, can improve lower limb muscle strength. However, if hemiplegic patients perform squats without supervision, the non-paretic leg tends to be used predominantly, which leads to decreased muscle activity in the paretic leg, resulting in asymmetry, learnt disuse of the paretic side<sup>1)</sup>, and concomitant weakness. Therefore, a method to facilitate quadriceps muscle activity on the paretic side during the double leg squat exercise is required.

When performing sit-to-stand motions, muscle activity varies according to the initial placement of the dominant foot in hemiplegic patients<sup>2)</sup>. Laufer et al.<sup>3)</sup> reported that lifting the non-paretic lower limb on a 10-cm-high step while standing increased the proportion of body weight on the paretic limb by 20% compared to symmetrical standing. Rocha et al.<sup>4)</sup> demonstrated that asymmetry was reduced during the sit-to-stand motion when the non-paretic leg was constrained by the inclusion of a “step-up” component.

However, muscle activity did not increase during the downward, maintenance, or upward phases of the squat exercise in hemiplegic patients.

The primary objective of this study was to characterize muscle activation during squats involving parallel foot placement and lifting of the non-paretic foot in hemiplegic patients. A secondary objective was to compare electromyographic (EMG) activity in the quadriceps during the downward, maintenance, and upward phases of the squat exercise.

## SUBJECTS AND METHODS

A total of 17 hemiplegic patients (9 males and 8 females) were recruited from the D Medical Center, Busan, Republic of Korea. The mean age of the patients was  $58.2 \pm 6.5$  years, and their mean height and weight were  $165.8 \pm 8.8$  cm and  $66.1 \pm 8.8$  kg, respectively. Subjects were eligible if they had a Berg Balance Scale (BBS) score of 35–45, a Korean-Modified Barthel Index (K-MBI) score of 60–85, a Modified Ashworth Scale (MAS) score between 1 and 2, and a Mini-Mental Status Examination-Korean version (MMSE-K) score  $>24$ . The mean BBS, K-MBI, MAS, and MMSE-K scores of the patients were  $41 \pm 3.4$ ,  $78.2 \pm 5.9$ ,  $1.5 \pm 0.5$ , and  $29.4 \pm 1.1$ , respectively. Hemiplegic patients were recruited following their first unilateral stroke, which was required to have occurred  $>6$  months previously. The mean post-stroke interval was  $10.4 \pm 5.2$  months. Prior to participation, all subjects read and signed an informed consent form that was approved by the Institutional Research Review Committee of the Inje University (Busan, Republic of Korea).

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To acquire EMG signals, surface EMG data were recorded using a Trigno wireless EMG system (Delsys, Inc., Boston, MA, USA). EMG data were collected from the rectus femoris (RF), vastus medialis oblique (VMO), and vastus lateralis (VL) muscles on the paretic side. The sampling rate and band-pass filter for the EMG signal were set at 1,000 Hz and 20–450 Hz, respectively. Data were analyzed using the EMGworks software package (ver. 4.0; Delsys, Inc.). Root mean square values were calculated for all raw data. To normalize the data, the reference voluntary contraction (RVC) was calculated for each muscle when subjects were in a comfortable standing position<sup>5</sup>).

Subjects performed the following two types of squat exercise: 1) parallel feet: feet parallel, shoulder-width apart, with the toes pointing directly forward; and 2) foot lifting: non-paretic foot lifted (normalized to 25% of the knee height). Subjects were instructed to flex the knee joint to 30° while standing for 3 s, until making contact with the target bar. Following the maintenance of 30° knee flexion for 3 s, the subjects returned to the starting position over a 3-s interval. All test trials were repeated three times, with a 1-min rest between trials to avoid fatigue. All EMG data are expressed as %RVC.

Significant differences between the downward, maintenance, and upward phases of the squat exercise, and between the parallel feet and foot lifting conditions, were examined using a 3 × 2 repeated-measures analysis of variance. All data were analyzed using the SPSS for Windows software package (ver. 18.0; SPSS Inc., Chicago, IL, USA);  $p < 0.05$  was taken to indicate statistical significance.

## RESULTS

During the downward, maintenance, and upward phases of the squat exercise, RF, VMO, and VL muscle activity was significantly greater with lifting of the foot than with the feet parallel ( $p < 0.05$ ). The activity of all three muscles increased significantly during the maintenance versus the downward and upward phases ( $p < 0.05$ ). Additionally, RF, VMO, and VL muscle activity was significantly greater during the upward versus the downward phase of the squat exercises ( $p < 0.05$ ; Table 1).

## DISCUSSION

The quadriceps muscle activity was increased during the squat exercise with the non-paretic foot lifted. This may have important clinical implications for muscle strengthening in hemiplegic patients.

Due to the presence of unilateral cerebral lesions, hemiplegic patients favor their non-paretic limb during bilateral movements such as sit-to-stand, standing, and parallel foot squats<sup>6</sup>). Strategies that selectively constrain movement can increase loading of the affected limb by altering the unaffected foot position during the sit-to-stand motion<sup>7</sup>). Brunt et al.<sup>2</sup>) reported that in hemiplegic patients, quadriceps activity in the paretic limb increased by 41% during foot lifting versus normal sit-to-stand conditions. Squat and sit-to-stand movements may be similar in terms of hip, knee, and ankle motion; the present results are in accordance with those of

**Table 1.** EMG activity (%RVC) in the rectus femoris, vastus medialis oblique, and vastus lateralis muscles during the squat exercise

Muscle	Phase	Feet parallel	Non-paretic foot lifted
Rectus femoris	Downward	207.5 ± 71.4	244.3 ± 76.5
	Maintenance	282.8 ± 97.3	363.5 ± 126.9
	Upward	251.8 ± 87.1	288.1 ± 91.7
Vastus medialis oblique	Downward	282.4 ± 116.5	423.8 ± 161.8
	Maintenance	381.3 ± 137.1	669.7 ± 255.6
	Upward	361.2 ± 133.0	586.6 ± 230.4
Vastus lateralis	Downward	257.7 ± 94.1	382.4 ± 150.8
	Maintenance	352.1 ± 86.3	604.1 ± 207.9
	Upward	354.0 ± 89.5	544.1 ± 156.0

our previous study, which involved sit-to-stand movement. Furthermore, squat exercises performed with the non-paretic foot lifted might facilitate paretic limb use by inhibiting the non-paretic limb. Therefore, we suggest that squats with the foot lifted allows for greater activation of the quadriceps muscle on the paretic side.

The squat exercise involves both downward and upward body movements, during which flexion and extension of the hip, knee, and ankle occur simultaneously<sup>8</sup>). Hemiplegic patients exhibit greater deficits in force in paretic muscles during concentric and isometric versus eccentric contractions<sup>9</sup>). Our data indicate that quadriceps activity is greater during the maintenance phase (i.e., isometric contraction) than during the upward phase of the squat exercise. Foot lifting during the squat exercise could increase the effectiveness of exercise programs aimed at restoring motor function in hemiplegic patients.

## REFERENCES

- 1) Taub E, Uswatte G, Mark VW, et al.: The learned nonuse phenomenon: implications for rehabilitation. *Eura Medicophys*, 2006, 42: 241–256. [[Medline](#)]
- 2) Brunt D, Greenberg B, Wankadia S, et al.: The effect of foot placement on sit to stand in healthy young subjects and patients with hemiplegia. *Arch Phys Med Rehabil*, 2002, 83: 924–929. [[Medline](#)] [[CrossRef](#)]
- 3) Laufer Y, Dickstein R, Resnik S, et al.: Weight-bearing shifts of hemiparetic and healthy adults upon stepping on stairs of various heights. *Clin Rehabil*, 2000, 14: 125–129. [[Medline](#)] [[CrossRef](#)]
- 4) Rocha AS, Knabben RJ, Michaelsen SM: Non-paretic lower limb constraint with a step decreases the asymmetry of vertical forces during sit-to-stand at two seat heights in subjects with hemiparesis. *Gait Posture*, 2010, 32: 457–463. [[Medline](#)] [[CrossRef](#)]
- 5) Lee MH, Shim JM, Park MC, et al.: A study of the stance limb during the crossing of obstacles of different heights by hemiplegic stroke patients. *J Phys Ther Sci*, 2010, 22: 317–321. [[CrossRef](#)]
- 6) Hesse S, Schauer M, Petersen M, et al.: Sit-to-stand manoeuvre in hemiparetic patients before and after a 4-week rehabilitation programme. *Scand J Rehabil Med*, 1998, 30: 81–86. [[Medline](#)] [[CrossRef](#)]
- 7) Gray CK, Culham E: Sit-to-stand in people with stroke: effect of lower limb constraint-induced movement strategies. *Stroke Res Treat*, 2014, 2014: 683681. [[Medline](#)]
- 8) Lee DK, Kim JS, Kim TH, et al.: Comparison of the electromyographic activity of the tibialis anterior and gastrocnemius in stroke patients and healthy subjects during squat exercise. *J Phys Ther Sci*, 2015, 27: 247–249. [[Medline](#)] [[CrossRef](#)]
- 9) Eng JJ, Lomaglio MJ, Macintyre DL: Muscle torque preservation and physical activity in individuals with stroke. *Med Sci Sports Exerc*, 2009, 41: 1353–1360. [[Medline](#)] [[CrossRef](#)]