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Frenkel's exercise on lower limb sensation and balance in subacute ischemic stroke patients with impaired proprioception

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Abstract

Background & Objective: Few reliable studies have used standardized outcome measures to examine the effectiveness of sensory interventions to treat somatosensory impairment. The aim of this study is to examine the effectiveness of Frenkel's exercise for improving lower limb sensation, balance, motor function, functional ambulation, and activities of daily living in subacute ischemic stroke patients with impaired proprioception. *Methods:* This retrospective cohort study enrolled 14 patients suffering subacute ischemic stroke between 7 to 30 days of onset who showed reduced proprioception in the lower limbs. They were divided into two groups: intervention group (performed Frenkel's exercise, 15 minutes per day, 15 days over a period of 3 weeks, n=7) and control group (received conventional physical therapy instead, n=7). Outcome measurements included the kinesthetic and light touch sensation subscales of the Nottingham Sensory Assessment (NSA) for the lower limb, the Korean version of the Berg balance scale (K-BBS), the Functional Ambulation Classification (FAC), the Motricity Index (MI), and the Korean version of the Modified Barthel Index (K-MBI). *Results:* Patients in both groups showed significant improvements on the kinesthetic and tactile sensation subscale of the NSA for the lower limb, the K-BBS, the FAC, and the K-MBI, but not the MI, from baseline to post-intervention at 3 weeks. When compared between the two groups, significant improvements were only seen in the kinesthetic sensation subscale of the NSA for the lower limb and the K-BBS ($p<0.05$).
Conclusions: Frenkel's exercise improves sensory and balance recovery among subacute ischemic stroke patients with impaired proprioception and minimal lower limb motor weakness.

Keywords: Brain infarction, exercise, postural balance, proprioception, sensation.

INTRODUCTION

Somatosensory impairment is common after stroke. According to a recent study, 7–53% of stroke patients have impaired tactile sensation, 31–89% have impaired stereognosis, and 34–64% have impaired proprioception.[1] Although sensory impairment tends to improve during the first 12 months following stroke[2], survivors are often left with a degree of deficit. Because somatosensory feedback is necessary for precise movement[3], impaired afferent inputs may lead to a lack of coordination, referred to as sensory ataxia. Although this is an important issue, it is frequently ignored and poorly treated, because the major focus of stroke rehabilitation protocols is restoration of impaired motor function.

Several sensory training related studies report improvement of impaired sensory function. Sensory retraining involves concentration and exposure to different sensory inputs to increase sensory awareness. Patients are asked to discriminate different textures, shapes, or

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weight, and are asked to focus on joint position, object recognition, and touch; they also receive education about sensory loss.[4-7] However, few reliable studies have used standardized outcome measures to examine the effectiveness of sensory interventions to treat somatosensory impairment.

A previous study suggests that intensive coordinative training is effective for patients with cerebellar ataxia. Ilg *et al*.[8] reported that patients with degenerative cerebellar disease showed improved motor performance and ataxia symptoms after 4 weeks of coordinative training, and that these improvements were sustained at follow-up, despite the progressive nature of the disease.[8] Thus, it was hypothesized that ataxia due to stroke would respond even better to coordinative training than ataxia due to degenerative cerebellar diseases. Here we examined the effect of coordinative training in patients with sensory ataxia due to stroke.

Frenkel's exercise[3], first devised by Heinrich Frenkel, is used to treat patients with tabetic ataxia. Frenkel's exercise is used to retrain proprioception and coordination, with particular focused on the lower limbs; therefore, it was assumed that it would improve lower limb sensation and function in stroke patients with impaired sensory function. Thus, the purpose of this study was to examine the utility of Frenkel's exercise for improving lower limb sensation, balance, motor function, functional ambulation, and activities of daily living (ADL) in subacute ischemic stroke patients with impaired proprioception.

METHODS

Study design and subjects

This retrospective cohort study was carried out in the Department of Rehabilitation Medicine at Asan Medical Center from September 2011 to August 2014. Patients admitted or transferred to the Department of Rehabilitation Medicine during this period were assessed for eligibility. Patients experiencing their first ischemic stroke and suffering hemiparesis between 7 to 30 days of onset and who had reduced proprioception (kinesthetic sensation subscale of the Nottingham Sensory Assessment < 12) of the lower limb were included. The following were excluded: (1) subjects with a proprioception deficit and impaired balance due to other diseases; (2) subjects with a cerebellar lesion or ataxia; (3) subjects who could not perform Frenkel's exercise due to cognitive impairment or lower limb weakness; and (4) subjects who were medically unstable.

Fourteen patients were enrolled in an intervention group (Frenkel's exercise, n=7) and a control group (no Frenkel's exercise, n=7). Subjects in both groups participated in a standard rehabilitation program comprising physiotherapy and occupational therapy, which included a range of movement-based exercises, strength training, shifting of weight from the nonparalytic to the paralytic side of the foot and vice versa, tone facilitation, balance, gait, and ADL training. The intervention group also performed Frenkel's exercise for 15 minutes per day for a total of 15 days over a period of 3 weeks. The control group received conventional physical therapy instead. The total rehabilitation time was similar for all patients.

The study was approved by Asan Medical Center's medical institutional review board and local ethics committee (IRB No. 2014-0943).

Frenkel's exercise

As mentioned above, Frenkel's exercise[3] is a coordination and proprioception exercise devised by Heinrich Frenkel for patients with tabetic ataxia. The treatment for tabetic ataxia is based upon educating the central nervous system through the accurate repetition of exercise with high levels of concentration. The exercises are performed in a recumbent position, in a sitting position, and in an erect position (Figure 1).

Patients began the exercises in the recumbent position. The exercises comprised: 1) hip flexion, extension, abduction, and adduction; 2) knee flexion and extension; 3) bringing the heel to the patella, the middle of the tibia, and to the ankle joint of the opposite leg; and 4) sliding the heel along the tibia. Exercises in sitting position comprised: 1) raising the thigh with the knee flexed and putting the foot firmly on the ground; 2) sitting down with the knees flexed and the body bent slightly forward; and 3) getting up with the feet fully touching the ground. Exercises in the erect position comprised: 1) walking forward; 2) walking sideways and returning to the original position; 3) walking backwards; 4) repeating the previous exercises using fixed short, medium, and long steps; 5) turning around an angle of 90 to 180 degrees; 6) walking in a zig-zag; 7) walking heel to toe; and 8) walking up and down stairs.

The exercises were practiced from one leg to both legs together in movement, and they were introduced gradually. Exercise progression depended upon the performance level of the individual patient. Therefore, some patients only repeated low level exercises, while some

Figure 1: Frenkel's exercises. (A) Hip abduction, and adduction in a recumbent position. (B) Knee flexion and extension of in a recumbent position. (C) Sitting down with knees flexed and body bent slightly forward. (D) Walking sideways and returning to the original position. (E) Turning around an angle of 90 degrees. (F) Walking heel to toe.

progressed to more difficult exercises. Frenkel's exercises began with moderate assistance and progressed until the patients required no assistance. Patients who did not have sufficient muscle strength or those who were unable to perform the movements precisely were assisted by their physical therapist. The patients were told to make the movements as slow as possible, and no exercise was repeated more than four times in succession to maintain concentration. All movements were initially performed with the eyes open so the patient could see what they were doing. The principle of Frenkel's exercise is to identify the type of exercise that best compensates for the loss of sensation, and to activate the mechanisms that control balance and multi-joint coordination. Verbal feedback was provided by the physical therapists during the exercises. These exercises trained the patients to use visual, somatosensory, and vestibular inputs to maintain balance and to avoid falling. As somatosensory improvement occurred, exercises were practiced with the eyes closed. Great care was taken to ensure patient safety throughout.

Outcomes

The patients were evaluated both before and after 3 weeks of rehabilitation by physical and occupational therapists. The primary outcome was the kinesthetic sensation subscale of the Nottingham Sensory Assessment (NSA) for the lower limb, which is designed to measure proprioceptive function. Secondary outcomes were the light touch sensation subscale of the NSA for the lower limb, the Korean version of the Beg Balance Scale (K-BBS) (trunk balance), the Motricity Index (MI) (motor function), the Functional Ambulation Classification (FAC) (ambulation), and the Korean version of the

Modified Barthel Index (K-MBI) (independence in ADL).

The NSA measures different somatosensory modalities in different body areas after stroke.[9] It assesses tactile sensation (light touch, pressure, pinprick, temperature, tactile localization, and bilateral simultaneous touch), kinesthetic sensation, stereognosis, and two point discrimination. In this study, only kinesthetic sensation (scored as 0-12) and light touch sensation (scored as 0-8) for hip, knee, ankle and foot were assessed. During testing, patients were given no feedback regarding performance. The K-BBS (scored as 0-56) is one of the most well-known balance measurement tools for stroke patients.[10] It evaluates the performance of an individual according to 14 items (one sitting and 13 standing items), all of which are related to balance functions that are frequently encountered in everyday life. The MI (scored as 0-100) is a feasible measure that is used to demonstrate strength in the upper and lower limbs[11] after stroke and is based on the ordinal six point scale of the Medical Research Council. The FAC (scored as 0-5) is a scale developed at Massachusetts General Hospital, which assesses the amount of human assistance (rather than devices), needed for ambulation. The K-MBI (scored as 0-100) is an assessment of ADLs and measures the degree of independence. It covers ten functional domains (activities): bowel control, bladder control, requiring help with grooming, toilet use, feeding, transfers, walking, dressing, climbing stairs, and bathing. In the measurements used, higher scores indicate better sensory (for NSA), balance (for K-BBS), motor strength (for MI), ambulation (FAC), and ADL (K-MBI).

Data regarding age, gender, time since stroke, and side of lesion were collected along with the Modified National Institute for Health Stroke Scale (mNIHSS) and the Mini-mental state examination (MMSE) scores.

Statistical analysis

Data were analyzed using SPSS (version 18.0, SPSS Inc, Chicago, IL) with a significance level at 0.05. Baseline characteristics were compared using Fisher's exact test (categorical variables) and the Mann-Whitney U test (continuous variables). Results were expressed as the mean ± standard deviation. Comparisons before and after treatment within each group were made using the Wilcoxon signed rank test. Treatment effects between the two groups were compared using the Mann-Whitney U test.

RESULTS

Baseline characteristics

Patients were recruited a mean 9.9±2.7 days after suffering stroke. The mean age was 65.2±7.8, the mean mNIHSS score was 6.7±2.7, the mean MMSE was 23.4±6.1, the mean kinesthetic sensation subscale of the NSA for the lower limb was 7.6±1.2, the mean tactile sensation subscale of the NSA for the lower limb was 4.8±1.3, the mean K-BBS was 14.1±2.3, the mean MI was 60.0±17.8 for the upper limb and 68.1±9.5 for the lower limb, the mean FAC was 1.3±0.5, and the mean K-MBI was 43.1±13.2. Side of the lesion of the stroke were 7 in right, and 7 in left in total. Major sites of the stroke lesion were the following: 2 middle cerebral artery territory, 1 basal ganglia, 1 internal capsule, 1 pons, and 2 medulla oblongata in the intervention group, and 1 anterior and middle cerebral artery territory, 1 middle cerebral artery territory, 1 basal ganglia and internal capsule, 2 thalamus, 1 pons, and 1 medulla oblongata in the control group. The baseline characteristics were well balanced between the two groups (Table 1).

Improvement in each group

Patients in both groups showed a significant improvement on the kinesthetic and tactile sensation subscales of the NSA for the lower limb, the K-BBS, the FAC, and the K-MBI after 3 weeks of rehabilitation. There was no significant difference between the groups in terms of improvement in the MI score for the upper and lower limbs (Table 2).

Intergroup comparisons

The intervention group showed more improvements than the control group in the kinesthetic sensation subscale of the NSA for the lower limb and the K-BBS ($p<0.05$). The intervention group also tended to show more improvements in the tactile sensation subscale of the NSA for the lower limb than the control group, although the differences were not statistically significant ($p=0.053$). The intervention group also showed more improvement than the control group according to the FAC and the K-MBI, however the differences were not significant (Table 3).

DISCUSSION

The present study showed that Frenkel's exercise could improve lower limb sensation and balance

Table 1: Baseline characteristics

Variables	Total (n=14)	Intervention group (n=7)	Control group (n=7)
Age (years)	65.2±7.8	63.6±10.1	66.9±4.8
Gender (Male:Female)	8 (57.1):6 (42.9)	3 (42.9):4 (57.1)	5 (71.4):2 (28.6)
Time since stroke (days)	9.9±2.7	9.0±2.4	10.7±2.8
Side of lesion (Right:Left)	7 (50.0):7 (50.0)	4 (57.1):3 (42.9)	3 (42.9):4 (57.1)
mNIHSS score	6.7±2.7	6.4±2.7	7.0±2.9
MMSE	23.4±6.1	23.7±6.4	23.1±6.4
NSA for the lower limb			
Kinesthetic subscale	7.6±1.2	8.0±1.4	7.1±0.9
Tactile subscale	4.8±1.3	5.3±1.6	4.3±0.8
K-BBS	14.1±2.3	14.0±2.8	14.3±1.8
MI			
Upper limb	60.0±17.8	60.0±19.0	60.0±18.1
Lower limb	68.1±9.5	68.3±9.6	68.0±10.1
FAC	1.3±0.5	1.4±0.5	1.1±0.4
K-MBI	43.1±13.2	45.7±10.3	40.4±16.0

Values are expressed as the mean ± standard deviation or as n(%).
mNIHSS: Modified National Institute for Health Stroke Scale; MMSE: Mini-mental state examination; NSA: Nottingham Sensory Assessment; K-BBS: Korean version of the Berg balance scale; MI: Motricity Index; FAC: Functional Ambulation Classification; K-MBI: Korean version of the Modified Barthel Index.

in subacute ischemic stroke patients with impaired proprioception and minimal lower limb motor weakness.

There was a significant improvement in the kinesthetic sensation subscale of the NSA for the lower limb ($p<0.05$) and a tendency of improvement in the tactile sensation subscale of the NSA for the lower limb ($p=0.053$) after

Table 2: Comparison between parameters pre- and post-exercise

	Intervention group (n=7)			Control group (n=7)		
	Pre-exercise	Post-exercise	P-value	Pre-exercise	Post-exercise	P-value
NSA for the lower limb						
Kinesthetic subscale	8.0±1.4	11.6±0.8	0.02*	7.1±0.9	9.0±1.3	0.02*
Tactile subscale	5.3±1.6	7.6±0.8	0.02*	4.3±0.8	5.1±1.1	0.04*
K-BBS	14.0±2.8	40.0±7.4	0.02*	14.3±1.8	23.7±6.6	0.02*
MI						
Upper limb	60.0±19.0	68.9±17.5	0.11	60.0±18.1	63.0±17.0	0.18
Lower limb	68.3±9.6	76.0±0.0	0.08	68.0±10.1	68.9±9.0	0.32
FAC	1.4±0.5	3.4±0.5	0.01*	1.1±0.4	2.6±0.8	0.01*
K-MBI	45.7±10.3	73.3±8.8	0.02*	40.4±16.0	59.3±8.1	0.02*

Values are expressed as the mean ± standard deviation.
NSA: Nottingham Sensory Assessment; K-BBS: Korean version of the Berg balance scale; MI: Motricity Index; FAC: Functional Ambulation Classification; K-MBI: Korean version of the Modified Barthel Index.
*$p<0.05$.

Table 3: Changes in each parameter in the intervention and control groups

	Intervention group (n=7)	Control group (n=7)	P-value
NSA for the lower limb			
Kinesthetic sensation	3.6±1.3	1.9±0.7	0.02*
Tactile sensation	2.3±1.4	0.9±0.7	0.053
K-BBS	26.0±6.4	9.4±5.4	<0.01*
MI			
Upper limb	8.9±11.5	3.0±5.1	0.46
Lower limb	7.7±9.6	0.9±2.3	0.32
FAC	2.0±0.6	1.4±0.8	0.13
K-MBI	27.6±7.4	18.9±9.8	0.07

Values are expressed as the mean ± standard deviation.
NSA: Nottingham Sensory Assessment; K-BBS: Korean version of the Berg balance scale; MI: Motricity Index; FAC: Functional Ambulation Classification; K-MBI: Korean version of the Modified Barthel Index.
*p<0.05.

Frenkel's exercise. The exercise was originally devised to improve kinesthetic sensation, but performing the exercise also stimulates tactile sensation. Furthermore, although different neural pathways are responsible for discriminative touch, flutter-vibration, proprioception, non-discriminative touch, innocuous thermal, and pain sensation[12], it is suggested that these pathways are integrated and interact with each other.[13] Therefore, while Frenkel's exercise improves proprioception, it may also improve these other pathways.

This study also suggests that patients who performed Frenkel's exercise also showed significant improvements in the K-BBS, which measures balance. Since balance and coordination depend on the complex circuitry within the cerebral cortex, cerebellum, basal ganglia, and peripheral motor and sensory pathways[14], improving afferent disability would be expected to lead to better balance. The intervention group showed no significant changes in the MI after treatment; therefore, it could be hypothesized that it was the improved sensory function that led to improvements in coordination and balance. Because all of the patients who could not perform Frenkel's exercise due to lower limb weakness were excluded in the study, there was no significant difference in the MI after 3 weeks of treatment due to a ceiling effect.

A significant improvements in the FAC (which assesses ambulation) and K-MBI (which assesses independence in ADL) in the intervention group were expected; however, these were not the case. The reason for inability to detect changes in FAC is probably due to small sample size, since the authors did not calculate the sample size to detect significance in FAC level. Also, FAC is a categorical scale scored on a scale from 0 to 5, unlike the other measurements used in this study, and it might be the reason. For the overall K-MBI score to be high, improvement in strength, ambulation and transfer is important; however, Frenkel's exercise focuses in coordination and proprioception, not strength. This might be the reason for nonsignificant differences in MI, FAC, and K-MBI scores between the two groups. Furthermore, the follow-up period of 3 weeks might be too short to detect a positive outcome. In a future study, using other functional ambulation measurements such as Six Minute Walk Test (6MWT) (instead of FAC), larger sample size, and longer follow-up period may draw different results.

There were some previous studies demonstrating the effect of Frenkel's exercise in different types of patients. Do. Nascimento *et al*.[15] showed improvements in coordination, balance and functional activities after 14 sessions of Frenkel's exercise lasting 50 minutes in one hemorrhage stroke patient with cerebellar ataxia. Rojhani-Shirazi *et al*.[16] demonstrated that 45 minutes of Frenkel's exercise, 5 days a week for 3 weeks, significantly improved balance in patients with type II diabetic neuropathy. Afrasiabifar *et al*.[17] also showed that 60 minutes of Frenkel's exercise, 3 sessions a week, for 12 weeks significantly improved balance in patients with multiple sclerosis. The duration of Frenkel's exercise in this study was relatively shorter (15 minutes per day for a total of 15 days over a period of 3 weeks) in comparison to the other studies[15-17];

however, there were also significant improvements in sensory and balance in stroke patients with impaired proprioception. To the best of our knowledge, this is the first study to demonstrate the effect of Frenkel's exercise in stroke patients with impaired proprioception.

There were other studies demonstrating effectiveness of sensory interventions, other than Frenkel's exercise, to treat somatosensory impairment after stroke. Carey *et al*.[18] showed that tactile discrimination and proprioception training led to improved texture and proprioceptive discrimination, and Morioka and Yagi[19] reported significant improvements in postural control when training stroke patients to discriminate materials of different hardness with plantar soles. However, the exercises in these studies are all very different and poorly described.

After a stroke, there is a period of natural sensory recovery. There are several theories explaining this recovery of somatosensory function in stroke patients. These include: recovery of damaged somatosensory pathways, reorganization of the peri-lesional area, and contributions made by the unaffected primary somatosensory cortex (SI), secondary somatosensory cortex (SII), posterior parietal cortex (PPC), and both affected and unaffected primary sensory-motor cortex (SM1).[12,20] This concept is known as brain plasticity. Evidence suggests that sensory training affects brain plasticity in stroke patients. For example, functional magnetic resonance imaging (fMRI) shows that proprioceptive input via the affected hand of patients with thalamic hemorrhage activates the unaffected SM1.[21] Also, fMRI and diffusion tensor imaging (DTI) revealed that natural reorganization occurred in two stroke patients after 2 weeks of upper extremity training program, which included manual manipulation, discrimination of temperature, weight, texture, and shape, and object recognition.[22] Also, 4 weeks of passive proprioceptive training of the wrist (20 minutes per day) led to modification of brain sensorimotor activity in subacute stroke patients, as evidenced by changes in the supplementary motor area (SMA), prefrontal cortex, and a contralesional network including SII and the ventral premotor cortex (PMv) upon fMRI.[23] Through above mentioned literatures, it is possible to predict that sensory training will not only affect sensory pathways in the brain, but also motor pathways and attention. Therefore, it is plausible that Frenkel's exercise will improve motor activity, even though there was no significant improvement in the MI in this study. Further studies examining patients with poor motor function would help to clarify this point.

There are some limitations regarding the generalizability of the results presented herein. First of all, the study is retrospective in nature, and included a small number of patients. Second, there was no information regarding somatosensory evoked potential (SEP), which is a good predictor of functional outcome.[24] Third, the study did not prove the recovery in the somatosensory tract using imaging methods such as DTI or fMRI. Finally, there was no long-term follow-up assessment.

In conclusion, the results of the present study suggest that performing Frenkel's exercise aids recovery of both sensation and balance in subacute ischemic stroke patients with impaired proprioception and minimal lower limb motor weakness. Although other studies have reported the use of sensory training methods for stroke patients, the exercises are all very different and poorly described. The descriptions of Frenkel's exercise are very precise and the movements are reproducible; therefore, this method should be considered when designing a rehabilitation program for subacute ischemic stroke patients showing reduced proprioception with minimal lower limb motor weakness. Further prospective and comprehensive studies are required to ensure a detailed understanding of the effects of Frenkel's exercise, including their clinical significance and the critical period during which the exercise should be performed.

DISCLOSURES

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