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Original Article

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# Obstacle Crossing Training for Improving Balance and Walking Functions After Stroke: Randomized Controlled Trial of Unaffected Limb Leads Versus Affected Limb Leads

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**| Abstract |**

**Purpose:** Obstacle crossing training is being used to improve the walking ability of stroke patients, but studies on which method is more effective when performing obstacle crossing training with an unaffected limb lead (OCT-ULL) and an affected limb lead (OCT-ALL) are not well known. As such, this study aims to compare the intervention effects of obstacle crossing training using unaffected limb leads (OCT-ULL) and obstacle crossing training using affected limb leads (OCT-ALL).

**Methods:** In total, 25 patients with chronic stroke were studied and assigned randomly to the obstacle crossing training with unaffected limb leads (OCT-ULL) group or the obstacle crossing training with affected limb leads (OCT-ALL) group. A lower extremity strength test, balance and gait test, and fall efficacy test were conducted as preliminary tests, and all patients participated in the intervention for 30 minutes a day, five days a week for four weeks, and the same preliminary tests were conducted post-intervention.

**Results:** Compared with the OCT-ALL group, the OCT-ULL group showed a significant improvement in the strength of the affected hip abductor muscle and in balance and gait, as well as in fall efficacy ($p<.05$).

**Conclusion:** This study suggested that applying the OCT-ULL training method in the obstacle crossing training of stroke patients is more effective for improving balance and gait functions than OCT-ALL.

**Key Words:** Obstacle crossing training, Unaffected limb leads, Balancing ability, Walking ability, Hemiplegia

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## Ⅰ. Introduction

Stroke patients lack motor control ability, which results in slow movement, compensatory action of the unaffected leg, proprioceptive sensory damage, and stiffness (Sakuma et al., 2014). Furthermore, 14-39% of hospitalized stroke patients have more than one fall incident, and 75% experience falls even after discharge. For stroke patients, fall prevention activities are as important as independent gait training (Walsh et al., 2017). Numerous stroke patients have experienced difficulties in obstacle crossing training, and obstacle-crossing failures result in a higher incidence of falls (Said et al., 2013). Moreover, most of the gait training for stroke patients is performed in a controlled indoor environment, but that does not improve walking ability in an outdoor environment. Community walking requires strategies for stroke patients to turn their heads or balance while walking, maintain stability against unexpected factors, and avoid or overcome obstacles (Shumway Cook et al., 2015). Patients are particularly afraid of falls while walking in the community, and generally encounter complex challenges such as crossing obstacles, changing direction, and walking on uneven ground. As patients face obstacles having various widths and heights, obstacle crossing training is a vital element for community walking (Robinson et al., 2011). The causes of falls include poor balance, space-time problems, decreased sensation, and decreased walking ability (Batchelor et al., 2012). Many treatment methods can improve balance and gait function in stroke patients. In particular, interventions that combine obstacle crossing and the treadmill walking may help improve the walking ability of patients with hemiplegic stroke and can possibly be used as an adjunct to routine rehabilitation therapy as a task-oriented practice based on community ambulation (Jeong & Koo, 2016).

It was also reported that the repetitive performance of various obstacle crossing training tasks supports stroke patients in maintaining a sense of psychological stability (Park & Kim, 2016). Accordingly, the limitations of daily life disappear when the fear of falling disappears, which further improves body functioning and reduces the risk of falling (Denkinger et al., 2010). Obstacle crossing training involving various widths decreases risk of falls among stroke patients and increases their confidence in balance; this, in turn, increases their ability to perform daily activities and enhances their quality of life (Iyigun, 2019). Conversely, the Gait Real-time Analysis Interactive Lab analyzed the obstacle crossing performance of chronic stroke patients and reported that it was not suitable to predict the risk of falling (Punt et al., 2017). In addition, according to a meta-analysis that compared the effects of general gait training and obstacle crossing training in stroke patients, the effectiveness of obstacle crossing training was found to be limited, and additional research was needed to confirm the magnitude of the effect (Muroi et al., 2019). In another study, the motion of crossing obstacles in stroke patients was measured using the VICON612 3D motion system and AMTI force plate. The study investigated whether it was more efficient to use the unaffected leg lead or the affected leg lead when performing obstacle crossings. When leading with the affected limb no changes in obstacle crossing speed or spatiotemporal variables were observed over the one month period. When leading with the unaffected limb, crossing speed significantly increased, and affected trail limb swing time and crossing step double support time reduced (Said et al., 2014).

As described above, various studies have been published on motion analysis, balance, gait and fall efficacy in relation to crossing obstacles in stroke patients. However, it is necessary to verify the effectiveness of the interventions in order to apply the obstacle crossing training to the clinical field. In addition, it is necessary to find out whether crossing obstacles is more effective using the unaffected limb or the affected leg. The hypothesis of this study is that performing obstacle crossing training by leading with the unaffected limb would be more effective in controlling the muscle strength of the affected lower limb, walking ability, balance control, and fall efficacy, than by leading with the affected limb. To verify this, this study applied the obstacle crossing training using unaffected limb leads (OCT-ULL) and the obstacle crossing training using the affected limb leads (OCT-ALL) for four weeks in chronic stroke patients.

## Ⅱ. Methods

### 1. Participants

This study was conducted on 25 patients with chronic stroke. The participants were divided into the OCT-ULL group (n=13), and the OCT-ALL group (n=12) by random sampling using a computer program. The selection criteria were as follows: those who received constant treatment for a gait disorder or balance disorder due to a chronic stroke, those who could walk more than 10m independently with or without assistive devices, those who did not have orthopedic problems in the lower extremities, those who scored 23 or higher in the Mini Mental Status Examination (Jeong & Koo, 2016), those without unilateral neglect, and those without cardiopulmonary and respiratory disease.

### 2. Study design

All participants received verbal and written information regarding the study and signed a consent form. This study was approved by the Cheongju University Institutional Review Board (IRB: 1041107-202004-HR-005-01). Participants were divided into groups as described above. The characteristics of the study participants are shown in Table 1. As a preliminary evaluation, muscle strength test using a Hand-held Dynamometer, balance test using the Modified Four Square Step Test (mFSST), gait test using the Timed Up and Go Test (TUGT), Dynamic Gait Index (DGI), and OPTOgait, and test for fall efficacy using the Activity-specific Balance Confidence Scale were conducted. In the intervention for the OCT-ULL group, an obstacle crossing training was performed by leading with the unaffected leg on the track, and the intervention for the OCT-ALL group was conducted using the same obstacle crossing training but by leading with the affected leg. Both groups participated in the training for 30 minutes a day, five times a week, for four weeks, and the number and height of obstacles were gradually increased according to the functional state of the participants. The 25 participants who completed the four weeks of training were evaluated using the same tests as those conducted at the preliminary stage by a skilled therapist with four years of clinical experience. All collected data were analyzed using a statistical program (Fig. 1).

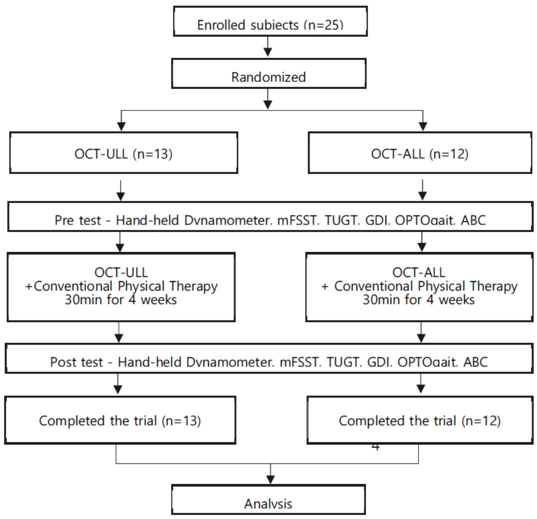


Fig. 1. Flow chart *Abbreviations*: OCT-ULL, Obstacle-crossing training with the unaffected limb leads; OCT-ALL, Obstacle-crossing training with the affected limb leads; mFSST, Modified Four Square Step Test; TGUT, Timed Up and Go Test; GDI, Dynamic Gait Index; ABC, Activity-specific Balance Confidence Scale.

## 3. Outcome measures

### 1) Strength of the hip abductor & flexor

The muscle strength of the flexor and abductor muscles of the hip joint was tested with a dynamometer (MicroFET2 hand-held dynamometer, Hoggan Health Industries, Inc, USA). The hip joint flexor was measured by bending the hip joint and the knee joint by 90 degrees each in a supine position, and the other leg was straightened to stabilize the pelvis (Karthikbabu & Chakrapani 2017). The dynamometer was placed at the distal third of the front of the thigh, and the patient was instructed to apply maximum force by pushing the dynamometer surface by bending the hip joint. Muscle strength was measured in pounds (lb). The measurement was conducted three times and the average value was calculated (Dubey et al., 2018).

### 2) Modified Four Square Step Test (mFSST)

The dynamic balance was measured using the mFSST. The intraclass correlation coefficient ranges between the test-retest reliability for stroke patients were 0.81 to 0.99 (Roos et al., 2016). The mFSST was performed up to three times. The participants completed mFSST by stepping clockwise from quadrants 1 to 4, then returning counterclockwise from quadrants 4 to 1. The participants were instructed to complete the stepping as fast as possible without stepping on the quadrant tape. The time required for the test was measured with a stopwatch.

### 3) Timed Up and Go Test (TUGT)

The gait ability was measured using the TUGT. The test-retest reliability of stroke patients was 0.944～0.987 (Chan et al., 2017). The participants were instructed to start from being seated upright and back on a chair without armrests. The measuring commenced when the tester said “start.” The participants stood up from the chair, walked three meters, returned to sit on the chair, and the measuring finished when their backs touched the chair. The time required for the test was measured with a stopwatch.

### 4) Dynamic Gait Index (DGI)

The advanced gait ability was measured using the DGI. The reliability between ICC and the tester for test-retest was 0.96 (An et al., 2016). There are eight items in the DGI: walking, walking while changing speed, walking while turning your head up and down and right, left, crossing obstacles, and climbing stairs. The DGI is based on a four-point scale from “0” (severe disability) to “3” (normal), with a total score of 24. If the score obtained after the test is less than 19 points, the patient is considered to have a high risk of falling and impaired functioning.

### 5) OPTOgait

A gait analyzer (OptoGait, MicrogateS.r.l, Italy) was used to test the gait pattern and gait amount, and the gait in relation to time and space. The walk analyzer was three meters long and had two transmission rods and a webcam (Logitech Webcam Pro 9000). The distance between the two rods was one meter, and it continuously received signals from the light emitting diodes of the transmitter. The participant’s gait was detected and transmitted through an infrared sensor and the temporal and spatial variables were collected. The participant’s gait sequence was stored in a webcam and later synchronized with recognition of errors for accurate gait measurements. The characteristics of gait analyzed in this study were the total stance (TS), total swing (TSW), and affected step time (AST). The collected data were processed using

OptoGait, version 1.5.0.0 software (MicrogateS.r.l, Italy). To minimize muscle fatigue, a one-minute break was given between measurements. The average value of three measurements was used.

6) Korean Version Activity-specific Balance Confidence Scale

The fall efficacy was measured using the Korean Version Activity-specific Balance Confidence Scale (ABC) (Jeong & Koo, 2016). The ABC is a self-report questionnaire to measure the fall efficacy during indoor and outdoor activities in daily life. This test has 16 items, with scores for each item ranging from 0% (no confidence) to 100% (complete confidence to not lose balance during activity). The internal consistency of ABC is 0.97, and the test-retest reliability was ICC = 0.98 (Park & Kim, 2016).

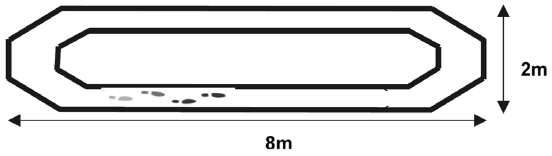


Fig. 2. Training Track.

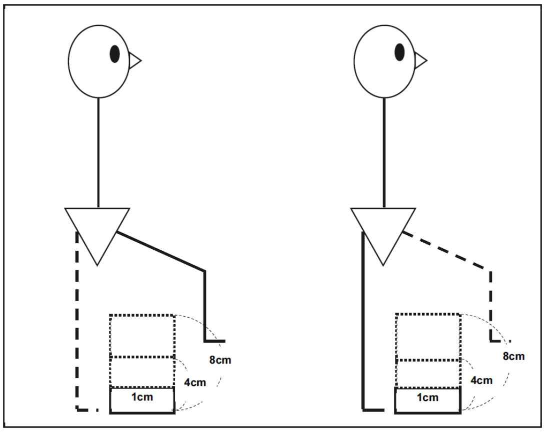


Fig. 3. Obstacle-crossing training *Abbreviations*: A, Obstacle-crossing training with the unaffected limb leads; B, Obstacle-crossing training with the affected limb leads; dotted linedotted line, affected limb; solid line, unaffected limb.

4. Intervention

1) Obstacle crossing training with the unaffected limb leads

All participants performed 30 minutes of conservative physical therapy and performed an additional intervention depending on the group. The OCT-ULL group performed obstacle crossing training by leading with the unaffected leg on a 20m track. Since it is supported by the affected leg and trained to pass, it was instructed to obstacle cross the pelvis to the unaffected leg without collapsing to activate the open muscle of the affected leg. The participants crossed one-centimeter-high obstacles installed at five-meter intervals (Figure 2). The number of obstacles was increased by placing them at 2.5m intervals if the participants maintained a stable and constant speed without touching the obstacles while walking. If participants maintained a stable and constant speed even after this, the height of the obstacle was increased to 4cm and 8cm to gradually increase the exercise intensity (Jeong & Koo, 2016). The obstacle crossing training was conducted for 30 minutes a day, five times a week, for four weeks. One-minute breaks were provided as required (Figure 3).

2) Obstacle crossing training with the affected limb leads

The OCT-ALL group performed obstacle crossing training by leading with the affected leg, and the training was conducted under the same conditions as for the OCT-ULL group. Since it is supported by the unaffected leg and trained to pass it over to the affected leg, it was instructed to balance the affected leg so that the affected leg does not get caught in an obstacle and does not fall on landing. An oval track with 8 m length x 2 m width, a walking width of 60 cm and a total length of 20 m was created using black insulating tape in the treatment room space. There were three types of obstacles, made of wood. All were 30cm wide and 2cm thick, but were 1cm, 4cm, or 8cm in height (Jeong & Koo, 2016).

### 5. Statistical analysis

For statistical analysis, the SPSS version 22.0 (SPSS Inc. US) program was used. Descriptive statistics and frequency analysis were performed for the general characteristics of the study participants. The test of normality for measurement results of the participants was performed using the Shapiro-Wilk test. The test confirmed that the measured results showed normality. Therefore, paired t-test and independent paired t-test were performed in each group to identify the differences within and between the groups. The statistical significance level of this study was set to $\alpha$=.05.

## Ⅲ. Results

Table 1 shows the general characteristics of the participants. There were no significant differences between the groups in gender, age, MMSE, duration of disease, assistive devices, and assistive braces of the two groups (p>.05). The two groups were randomly assigned, and there was no significant difference between the groups in the initial evaluation. Muscle strength measurement showed that the hip abductor muscle of the OCT-ULL group significantly improved compared to the OCT-ALL group, and the hip flexor muscle showed a more significant increase in the OCT-ALL group than in the OCT-ULL group (p>.05). As a result of mFSST, the dynamic balance ability significantly improved in the OCT-ULL group (p<.05). Gait ability improved in both TUGT and DGI in the OCT-ULL group as opposed to the OCT-ALL group (p>.05). By OPTOgait measurement, a significant improvement was found in only TS in the OCT-ULL group after the intervention (p>.05). Fall efficacy significantly improved in the OCT-ULL group (p>.05) (Table 2).

## Ⅳ. Discussion

The purpose of this study was to investigate the more effective obstacle crossing method by applying OCT-ULL and OCT-ALL for four weeks in chronic stroke patients. By measuring muscle strength using a dynameter, the

**Table 1. Characteristic of participant**

| | OCT-ULL group(n=13) | OCT-ALL group(n=12) | t | P value |
|---|---|---|---|---|
| Age(year) | 66.75±5.32 | 65.16±7.29 | -0.60 | .552 |
| male/female | 7/6 | 7/5 | -0.39 | .693 |
| Onset(month) | 11.5±2.39 | 12.41±2.81 | 0.86 | .395 |
| Side affected(left/right) | 7/6 | 6/6 | -0.39 | .692 |
| MMSE | 25.75 | 25.83 | -0.65 | .530 |
| Assistive devices, none/single cane | 4/9 | 4/8 | 0 | 1 |
| Ankle foot othosis, yes/no | 4/9 | 4/8 | -0.48 | .310 |

*Abbreviations*: OCT-ULL, Obstacle-cross training with the unaffected limb leads; OCT-ALL, Obstacle-cross training with the affected limb leads; Data are presented as mean ± SD; MMSE, Mini mental state examination.

Table 2. Pre- to post-intervention changes observed in the two study groups

| Subdivision | OCT-ULL group | | OCT-ALL group | | | |
|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | t | P value |
| HA(lb) | 10.0±3.5 | 14.1±3.0* | 10.5±2.9 | 11.0±3.0 | 2.11 | 0.03† |
| HF(lb) | 10.0±1.3 | 10.4±1.3 | 11.5±3.4 | 13.6±3.2* | 2.33 | 0.02† |
| mFSST(s) | 59.8±31.5 | 52.1±29.4* | 59.7±26.3 | 59.4±26.4 | 2.23 | 0.03† |
| TUGT(s) | 34.1±15.1 | 27.2±12.8* | 34.2±14.8 | 33.9±15.1 | 2.13 | 0.04† |
| DGI(0-3) | 1.4±0.7 | 2.3±0.6* | 1.5±0.5 | 2.1±0.7* | 2.14 | 0.03† |
| TS(%) | 69.8±2.1 | 67.1±2.4* | 69.4±2.1 | 69.3±2.0 | 0.67 | 0.03† |
| TSW(%) | 30.1±2.1 | 32.9±2.4* | 32.2±2.6 | 32.8±2.8 | 0.28 | 0.77 |
| AST(s) | 2.1±0.6 | 1.8±0.6* | 1.8±0.3 | 1.6±0.3* | 1.27 | 0.20 |
| ABC(0-100) | 61.5±6.0 | 69.1±6.0* | 62.9±7.4 | 64.3±7.0* | 3.06 | 0.00†` |

*Abbreviations*: HA, strength of the affected hip abductor; HF, strength of the affected hip flexor; mFSST, modified Four Square Step Test; TUGT, Timed Up and Go Test; DGI, Dynamic Gait Index; TS, total stance; TSW, total swing; AST, affected step time; ABC, Activity-specific Balance Confidence.
*Significant difference within each group ($p<.05$). †Significant difference between groups ($p<.05$).

affected hip joint abductor muscle was found to be significantly improved in the OCT-ULL group. It has been reported that the improvement of muscle strength of the affected hip abductor muscle in stroke patients helps to improve the motor control for the torso and lower extremities, balance, walking speed, and daily activities (Dubey et al., 2018). The muscle strength of the affected hip joint abductor muscle is assumed to have improved in the OCT-ULL group as the affected leg provides support when the patients cross the obstacle with the unaffected leg. However, the OCT-ALL group members showed significant improvement in the affected hip flexor muscles and were reported to use the hip flexors when crossing high obstacles (Chou et al., 2001). Said et al. also reported that the motion of the joint increased after obstacle training in hemiplegic patients, and that the bending angle of the hip joint improved (van der Krogt & Delp, 2012). The OCT-ALL group is thought to have gained improvement in the strength of the hip flexor muscles of the affected leg because support is provided by the unaffected limb and crossing the obstacle is performed with the affected leg. found that weakness of the plantar flexor, hip joint abductor muscle, and hip flexor muscle responded most sensitively to gait among the lower extremity muscles, and that the weakness of these muscles further deteriorates the weakened muscles and leads to a compensatory action (van der Krogt & Delp, 2012). Therefore, a follow-up study is suggested to accurately measure the degree of muscle strength improvement of the affected hip joint's abducting and flexing muscles, and the plantar flexing muscles during obstacle crossing training.

A modified quartile step test was used to measure the dynamic balance ability. The test showed that there was a significant improvement in the OCT-ULL group compared to the OCT-ALL group. Lu et al., had reported that repetitive hurdle crossing training had a positive effect on improving balance. It has also been reported that strengthening of the affected hip joint abductor muscle reduces asymmetric support time and improves balance (Fujisawa & Takeda, 2006). The muscle strength of the affected hip joint abductor muscle is assumed to have been strengthened and balance is thought to have been improved in the OCT-ULL group as this group crossed over obstacles by supporting their weight with the affected leg.

In order to evaluate the gait ability, the spatiotemporal elements were measured using the TUGT, DGI and Optogait system. The TUGT and DGI showed significant differences in the comparison between the groups. In the examination through the Optogait system, the OCT-ULL group showed statistical significance between groups in the total support ratio. Such results are consistent with the results of a previous study that reported that the swing time and double support time increased when an obstacle was crossed by leading with the unaffected leg in one-time motion analysis (Said et al., 2014). The gait is reported to receive the worst damage when the plantar flexor, hip abductor, and hip flexor muscles become weakened. Therefore, reports suggest that it may be most useful to target such muscles for muscle strengthening programs (van der Krogt & Delp, 2012). Gluteus medius and gluteus minimus, together with tensor fasciae latae muscle, play an important role in pelvic stability during the intermediate support phase in the gait cycle (Frigotto et al., 2019). The OCT-ULL group experienced a gradual increase in the difficulty of crossing the obstacle which strengthened the affected hip joint abductor muscle and the intermediate support was improved, which is assumed to have significantly improved the total support ratio and walking ability. Total swing and affected step time had significant results before and after the intervention, but there was no significant improvement between the two groups. Kim (2015) reported that the tibialis anterior muscle, calf muscle, and trunk muscle can affect the stance phase, swing phase, and certain temporal factors of the leg. In this study, it is not a training targeting trunk muscles, tibialis anterior muscle, and calf muscles, and it is not known whether it affects muscle improvement, so it is thought that there were no significant results between the two groups. Most of gait training for stroke patients is generally performed in a controlled indoor environment. However, indoor gait training is not sufficient for the gait functioning in the outdoor environment[4]. Therefore, through monitoring, further research will be needed to investigate if there is an effect in real-life community walking.

As a result of evaluating fall efficacy, a significant improvement was noted in the OCT-ULL group as opposed to the OCT-ALL group. Said et al. reported that stroke patients experienced difficulties in crossing obstacles of various widths and heights, and stroke patients who failed to cross the obstacle had a higher incidence of falls (Said et al., 2013). Furthermore, stroke patients were reported to have a fear of falling in the community because they encountered obstacles of varying widths and heights (Robinson et al., 2011). It is considered that significant results have been obtained in improving performance ability and fall efficacy in this study as the participants experienced numerous obstacles of various heights through the obstacle crossing training. This study confirmed that the group that applied obstacle-crossing training to chronic stroke patients with dry legs can be a more effective intervention in improving lower limb muscle strength, balance, gait ability, and fall efficacy compared to the group that trained to cross obstacles. The affected leg should be more safely balanced on the ground as it leads over the obstacle with the unaffected leg. As a result, it is believed that the hip joint abductor muscle and balance ability are improved, improving the support of the affected leg, and thereby improving the fall efficacy. Some limitations of this study should be considered. First, it was conducted only on patients in a specific area, and the number of participants was small. Second, it was difficult to control the influence of self-exercise performed during the study. Consequently, there is a difficulty in generalization. Future studies will need to overcome these limitations.

## Ⅴ. Conclusions

According to the results, the muscle strength test showed a significant difference in the affected hip flexor muscle in the OCT-ULL group, and the affected hip flexor muscle was also significantly improved in the OCT-ALL group. In the dynamic balance evaluation through mFSST, the OCT-ULL group showed a significant improvement compared to the OCT-ALL group. In the evaluation of gait ability through TUGT and DGI, there was a significant improvement in the OCT-ULL group compared to the OCT-ALL group. In gait analysis including spatio-temporal factors using the Optogait system, the OCT-ULL group showed a significant improvement in the total support ratio compared to the OCT-ALL group. In terms of fall efficacy, the OCT-ULL group showed statistical significance compared to the OCT-ALL group. Therefore, it was confirmed that the OCT-ULL method was more effective than the OCT-ALL method in improving the affected limb muscle strength, balance, gait, and fall efficacy of stroke patients.

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