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ORIGINAL ARTICLE

Effects of a Balance Exercise Assist Robot on Older Patients with Hip Fracture: A Preliminary Study

Eiko Takano[1] · Kenichi Ozaki[2] · Kenji Satoh[2] · Koki Kawamura[2] · Mathieu Maltais[3,4] · Izumi Kondo[1,2]

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Abstract

Purpose The aim of this study was to determine whether exercises using a balance exercise assist robot (BEAR) improved balance function in older patients with a hip fracture whose ability to perform activities of daily living (ADL) had almost plateaued.

Methods Participants were 27 older patients (3 men, 24 women; mean age 81.0 ± 6.3 years) with a hip fracture whose ability to perform ADL had almost plateaued and who were about to be discharged. All participants performed exercises using the BEAR for 20 min a day, 6 days a week, for 2 weeks before leaving the hospital. We assessed the following at pre- and post-exercise: the Timed Up and Go test (TUG), the Berg Balance Scale (BBS), the functional reach test (FRT), the standing test for imbalance and disequilibrium, functional independence measure scores (total and walking ability), preferred gait speed, and muscle strength of the lower extremities.

Results Significant differences were observed between pre- and post-exercise for all measures, including TUG (pre: 21.9 ± 17.7 s, post: 17.4 ± 13.6 s, $P < 0.001$), BBS (47.0 ± 8.1 points, 50.6 ± 6.3 points, $P < 0.001$), and FRT (22.4 ± 6.2 cm, 24.8 ± 6.7 cm, $P = 0.005$).

Conclusion In older patients with hip fracture whose ability to perform ADL has almost plateaued, adding the BEAR exercises to rehabilitation programs could improve balance function better than traditional programs alone. Balance exercises using a robot may be an effective measure to prevent falls at home after a hip fracture.

Keywords Balance · Exercise · Hip fracture · Older patients · Robot

1 Introduction

The main purpose of convalescent rehabilitation wards in Japan is to provide effective rehabilitation for patients with cerebrovascular disease or fracture and improve their ability to perform activities of daily living (ADL); this helps patients avoid a prolonged bedridden status and return home [1]. In Japan, older patients with a hip fracture generally undergo surgical treatment, after which about 80% enter a convalescent rehabilitation ward [2]. In the ward, they perform ambulatory movements as well as intensive physical strength training, focused on improving the capacity to perform ADL [3].

However, even when older patients with a hip fracture participate in intensive rehabilitation, they remain at an increased risk for subsequent hip fractures. According to our unpublished survey, 18.4% of these patients experienced a fall within 1 year after discharge. Monaco et al. reported that 20% of community-dwelling women with a fall-related fracture of the hip sustained at least 1 fall during the 6-month follow up [4]. Moreover, bilateral hip fractures occur within 5 years in more than 70% of such patients [5]. Therefore, it may be necessary to add another balance exercise for these patients in the convalescent rehabilitation ward.

✉ Eiko Takano
eikoath@ncgg.go.jp

1 Center of Assistive Robotics and Rehabilitation for Longevity and Good Health, National Center for Geriatrics and Gerontology, 7-430, Morioka-cho, Obu, Aichi 474-8511, Japan

2 Department of Rehabilitation Medicine, National Center for Geriatrics and Gerontology, Obu, Japan

3 Faculté de Médecine Et Sciences de La Santé, Centre de Recherche Sur Le Vieillissement, Sherbrooke, QC, Canada

4 Faculté Des Sciences de L'Activité Physique, Université de Sherbrooke, Sherbrooke, QC, Canada

A few recent studies have reported that exercises using a balance exercise assist robot (BEAR) improved balance function [6–8]. Ozaki et al. reported that exercises using the BEAR improved dynamic balance among community-dwelling frail or pre-frail elderly individuals more than traditional exercises alone [6]. Ozaki et al. also reported that exercises using the BEAR were effective for improving balance function in patients with a central nervous system disorder [7]. We hypothesized that exercises using the BEAR might be effective for improving balance function in older patients with a hip fracture.

In general, older patients with a hip fracture leave the convalescent rehabilitation ward when their ability to perform ADL has almost plateaued. The aim of the present study was to determine whether exercise using the BEAR improves balance function in older patients with a hip fracture whose ability to perform ADL had almost plateaued using traditional training.

2 Methods

This was an exploratory, single-arm trial conducted to investigate the effects of exercises using a BEAR in older inpatients with a hip fracture whose ability to perform ADL had almost plateaued. The Medical Ethics Committee of the National Center for Geriatrics and Gerontology approved this study (No. 810-3). The study conformed to the provisions of the Declaration of Helsinki (as revised in Brazil, 2013). All participants provided written informed consent.

2.1 Participants

The participants were 27 older inpatients with hip fracture (3 men, 24 women; mean age 81.0 ± 6.3 years). Their physical therapist (PT) and occupational therapist (OT) judged that their ability to perform ADL had almost plateaued.

The inclusion criteria were as follows: (1) had undergone surgery for a hip fracture; (2) could walk independently; and (3) had been admitted to our center's rehabilitation ward between June 2015 and October 2017. The exclusion criteria were: (1) resting systolic blood pressure > 180 mmHg or diastolic blood pressure > 120 mmHg; (2) resting heart rate > 120 beats/min; (3) restricted activity owing to a cardiopulmonary function disorder; (4) a severe hearing or visual impairment; and (5) severe cognitive impairment (< 20 points on the Mini-Mental State Examination [9]).

2.2 Instruments

The BEAR (Toyota Motor Corporation, Toyota, Japan) was developed in collaboration with the Toyota Motor Corporation (Toyota, Japan) and Fujita Health University (Toyoake, Japan). This system consisted of a robot (boarding equipment), a game display, and a safety harness. A rider moved the robot and controlled his/her avatar on the games. The robot consisted of 2 steps with the load sensor, 2 wheels with in-wheel-type motors, and a handle attached to the center pillar (Fig. 1). The robot maintained a horizontal position by itself because it was controlled by an inverted pendulum system. The rider stood on the steps and grasped the handle of the robot (Fig. 1). As the robot moved in accordance with the position of the rider's center of gravity (COG), the rider controlled the COG using the ankle and hip joints. When the COG was situated in front of the steps, the wheel rotated in the same direction, and the robot was moved forward until the COG returned to the center on the steps. Conversely, if the COG was behind the steps, the robot was moved backward. If the rider wanted to turn left, the rider moved the COG to the right because the wheels turn in the opposite direction from the COG. If the rider wanted to turn right, the rider moved the COG to the left.

The exercises using the BEAR consisted of 3 games: tennis, slalom (skiing), and rodeo (Fig. 1). The length of the exercises totaled 20 min/day. In the tennis and slalom games, the rider controlled the avatar by actively moving the robot back/forth and left/right using the COG. In the rodeo game, the rider performed a distribution exercise by keeping the COG's position and resisting the robot motion. The level of difficulty was adjusted to suit the individual, and the rider was induced by the BEAR to perform repetitive movements automatically.

To ensure safety during the exercises, we prepared a 2.4 m × 2.0 m space in the exercise room for exclusive use for participants. In addition, participants wore the safety harness to limit fall risk (no lifting force was applied to reduce weight-bearing).

2.3 Interventions

After the PT and OT judged that participants' ability to perform ADL had almost plateaued, they added exercises using the BEAR an extra 6 days a week for 2 weeks to the rehabilitation program. They performed a total of 180 min daily rehabilitation: 20 min of the BEAR exercises and 160 min of the rehabilitation program. In the rehabilitation program, participants underwent training to improve their ability to perform instrumental ADL (IADL), such as house cleaning, cooking, walking outside, and walking while carrying a handbag. In addition, they learned about home exercise programs and effective measures to prevent falls.

2.4 Outcome Measures

In this exploratory study, we assessed the following measures before starting the BEAR exercise (baseline) and the

Fig. 1 The system of the balance exercise assist robot (BEAR). The BEAR system consisted of a robot (boarding equipment), a game display, and a safety harness. A rider moved the robot and controlled his/her avatar in the games. The robot consisted of 2 steps with the load sensor, 2 wheels with in-wheel-type motors, and a handle attached to the center pillar. The robot maintained a horizontal position by itself because it was controlled by an inverted pendulum system. The exercises using the BEAR consisted of 3 games: tennis, slalom (skiing), and rodeo. The length of the exercises totaled 20 min/day. In the tennis and slalom games, the rider needed to move the center of gravity (COG). For the rodeo game, the rider kept the COG's position by resisting the robot motion

day after the last session of the BEAR exercise (2w): the Timed Up and Go (TUG) test [10], the Berg Balance Scale (BBS) [11], the Functional Reach Test (FRT) [12], the Standing Test For Imbalance and Disequilibrium (SIDE) test [13], the Functional Independence Measure (FIM) (total and walking ability) [14], preferred gait speed, muscle strength of the lower extremities, and the Falls Efficacy Scale-International (FES-I) [15]. Furthermore, we assessed FIM and SIDE every 2 weeks during the stay in the convalescent rehabilitation ward.

TUG assesses the time it takes patients to stand up, walk 3 m, turn around, walk back, and sit back down [10]. Older adults who take longer than 13.5 s to complete the TUG have a high risk for falls [16]. BBS determines changes in functional standing balance over time. A subject's performance on each of 14 tasks of the BBS is graded on a 5-point scale ranging from 0 to 4 based on speed, stability, or degree of assistance required to complete the task. The task scores are summed to give a total BBS score out of a possible 56 points, with higher scores representing better balance [11]. FRT measures the difference between arm's length and maximal forward reach, with longer lengths representing better standing balance [12]. SIDE assesses standing balance on a 6-point scale. The levels are based on how well a patient can maintain a sequence of postures (wide-base, narrow-base, tandem standing, and single-foot stance); higher levels represent better standing balance [13]. We also measured the participants' preferred gait speed. Participants walked 14 m at self-selected, preferred gait speeds. We measured the time taken for the 10 m in the middle. FIM measures the ability to perform ADL based on a 7-point scale. It is composed of 18 items (a 13-item motor subscale and a 5-item cognition subscale). The total score ranges from 18 to 126, with higher scores representing better functional ability [14]. The strength of the gluteus medius, quadriceps femoris, and gastrocnemius was measured using a dynamometer (μTas F-100; Anima Corp., Tokyo, Japan). The positioning of the joints for each measurement followed the methods proposed by Bohannon [17]. FES-I assesses the level of concern about falling when carrying out each activity on a 4-point scale (1 = not at all concerned, 4 = very concerned). It is composed of 16 items, and a total score ranges from 16 to 64, with higher scores representing a greater level of concern [15]. The participants performed each measure twice except for FIM and FES-I, which were assessed only once, and the best result was used.

2.5 Statistical Analysis

Because of the exploratory nature of the study, we did not perform a formal sample size calculation. Data from this study are expected to inform sample size and power calculations for a large trial in the future.

At first, we performed a normality test of data by Shapiro–Wilk and compared outcomes between baseline and 2w using a paired *t* test or Wilcoxon signed-rank test. In addition, we created the historical control group using propensity score matching. In the historical control group, FIM and SIDE were assessed at 4w before discharge and at discharge, and were evaluated on the same number of days as − 2w and 2w in the BEAR group, counting from discharge. We compared the total FIM points between − 2w and 2w in the two groups using two-way repeated-measures analysis of variance, and compared SIDE between − 2w and 2w in each group using the Wilcoxon signed-rank test. The confounders selected were age, sex, MMSE, and total FIM score at − 2w. Statistical analysis was conducted using SPSS Statistics (version 25 for Mac; IBM, Chicago, IL, USA), with the significance level set at $P < 0.03$.

3 Results

Table 1 shows participants' characteristics at baseline. The mean number of days from the fracture to starting exercises using a BEAR was 50.6 ± 13.9 days (range, 29–80 days). All participants could walk with or without walking aids such as a cane, an orthosis, or a walking frame.

Table 2 shows a comparison of outcomes between baseline and 2w. Significant differences were observed for the following outcomes: TUG, BBS, FRT, SIDE, FIM (total and walking ability), preferred gait speed, and strength of the gluteus medius (injured and non-injured side), and the gastrocnemius on the injured side. No significant differences were observed for FES-I or the strength of the quadriceps femoris and the gastrocnemius on the non-injured side.

After propensity score matching, characteristics at − 2w did not differ significantly between the BEAR (n = 21, 2 men and 19 women) and the control group (n = 21, 5 men and 16 women): age, 81.5 ± 5.7 years vs 82.8 ± 5.9 years, respectively; total FIM score, 108.2 ± 9.6 points vs 107.7 ± 9.7 points, respectively. There were no significant differences in the time effect, the group effect, and interactions of FIM. There was a significant difference in SIDE between − 2w and 2w in only the BEAR group ($p < 0.01$) (Table 3, Fig. 2).

Table 1 Characteristics of 27 participants when starting the balance exercise assist robot (BEAR) exercises (baseline)

Characteristics	(N = 27) Mean (SD)
Age, years	81.0 (6.3)
Sex, n (%)	
Male	3 (11.1)
Female	24 (88.8)
Height, cm	149.2 (8.5)
Weight, kg	48.5 (7.3)
MMSE, points	25.7 (3.8)
Comorbidities, n (%)	
Diabetes	13 (48.1)
Other fracture except for hip fracture	7 (25.9)
Osteoarthropathy	5 (18.5)
Cerebrovascular disease	5 (18.5)
Dementia	2 (7.4)
Parkinson disease	1 (3.7)

SD standard deviation, *MMSE* the Mini-Mental State Examination

Table 2 Comparison of outcome measures between baseline and the day after the last session of balance exercise assist robot (BEAR) exercises (2w) (n = 27)

Outcome measures	Baseline		2w		*P* value
	Mean	SD	Mean	SD	
TUG, s	21.9	17.7	17.4	13.6	< 0.001
BBS, points	47.0	8.1	50.6	6.3	< 0.001
FRT, cm*	22.4	6.2	24.8	6.7	0.005
SIDE, level**	3.0	2.0	4.0	1.0	0.010
FIM					
Total, points	112.6	7.3	113.7	7.2	0.002
Walking ability, points	5.9	0.4	6.2	0.6	0.002
Preferred gait speed, m/s*	0.7	0.3	0.9	0.3	< 0.001
Strength, kg-f					
Gluteus medius					
Injured side	9.2	5.1	10.5	4.6	0.012
Non-injured side	8.6	4.0	9.8	4.7	0.028
Quadriceps femoris					
Injured side	14.5	7.1	16.3	8.6	0.038
Non-injured side	15.2	7.8	16.2	8.8	0.086
Gastrocnemius					
Injured side	18.1	10.7	22.6	12.5	0.015
Non-injured side	18.6	11.0	21.2	10.7	0.049
FES-I, points	32.0	11.3	31.7	11.3	0.909

Baseline, starting the BEAR exercises; *2w* the day after the last session of the BEAR exercise; *TUG* the Timed Up and Go test, *BBS* the Berg Balance Scale, *FRT* the Functional Reach Test, *SIDE* the Standing Test for Imbalance and Disequilibrium, *FIM* the Functional Independence Measure, *FES-I* the Falls Efficacy Scale-International, *SD* standard deviation

*FRT and preferred gait speed were analyzed using a paired *t* test. **SIDE is presented as median and interquartile range (IQR). All others variables were analyzed using the Wilcoxon signed-rank test

Table 3 Comparison of the total FIM points and the SIDE level between the BEAR group and the historical control group

	BEAR group (n = 21)				Control group (n = 21)			
	− 2w		2w		− 2w		2w	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age, years	81.5	5.7			82.8	5.9		
Sex, n (%)								
Male	2	9.5			5	23.8		
Female	19	90.5			16	76.2		
Total FIM, points	108.2	9.6	113.9	7.6	107.7	9.7	111.0	12.5
SIDE, level	2.6	0.9	3.7	0.8	2.8	1.1	3.3	1.5

SD standard deviation, *FIM* the Functional Independence Measure, *SIDE* the Standing Test for Imbalance and Disequilibrium

− 2w, 2w before starting the BEAR exercises and 4w before discharge; 2w, the day after the last session of the BEAR exercises and at discharge

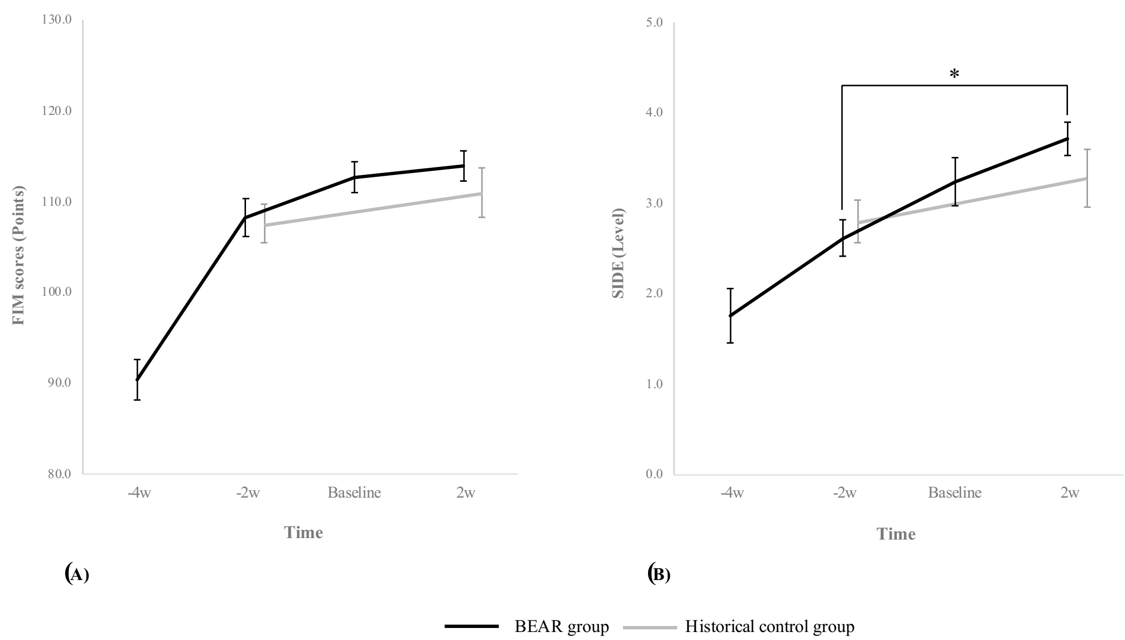

Fig. 2 Change in (A) the Functional Independence Measure (FIM) and (B) the Standing Test for Imbalance and Disequilibrium (SIDE) for 8 weeks. The figure indicates the mean (standard error) change in the total FIM points and the SIDE level for 8 weeks. In the BEAR exercise group, those were assessed at 4w and 2w before starting the BEAR exercises (− 4w and − 2w), baseline, and the day after the last session of the BEAR exercises (2w). In the historical control group, they were assessed at 4w before discharge and at discharge, and were evaluated on the same number of days as − 2w and 2w in the BEAR group, counting from discharge. The two groups were assessed on the same number of days counting from discharge. − 4w, 4w before starting the BEAR exercises; − 2w, 2w before starting the BEAR exercises, and 4w before discharge; 2w, the day after the last session of the BEAR exercises, and at discharge; $*p < 0.01$

4 Discussion

In this study, we compared outcomes before and after the BEAR exercises to determine the effects of this technology on older patients with a hip fracture whose ability to perform ADL had almost plateaued with traditional rehabilitation programs. We found that adding the BEAR exercises to rehabilitation programs could improve balance function, walking ability, and muscle strength of the lower extremities. In particular, balance function improved more than with traditional programs alone. However, FES-I scores were high and did not change, and participants had a fear of falling. Gazibara et al. reported that in older adults who were recruited at a community health center, the average FES score was significantly higher in fallers than non-fallers (19.2 ± 13.1 vs 14.2 ± 8.3, respectively) [18]. Among people with a higher number of falls, higher self-efficacy and low balance ability tend to increase the risk for additional falls. Thus, it is important for such patients to improve their balance ability before discharge from the hospital.

We started the BEAR exercise after the PT and OT judged that the patient's ability to perform ADL had almost plateaued. The total FIM score was not significantly different between − 2w and 2w, and patients' abilities to perform ADL had plateaued significantly. However, SIDE improved by adding the BEAR exercises, compared to traditional programs alone. Moore et al. reported that individuals with chronic stroke, whose motor functions had plateaued according to the PT, showed improvement in motor function when they were provided intensive motor tasks [19]. Demain et al. indicated that later recovery was possible after the diagnosis of a functional plateau [20]. In the BEAR exercises, the rider needed to control the COG using the ankle and hip joints, because the robot moved in accordance with the position of the rider's COG. Even if the ability to perform ADL has plateaued, special exercises like those provided by the BEAR might improve motor functions, especially balance.

The purpose of convalescent rehabilitation wards in Japan is to allow patients to improve their ability to perform ADL quickly. Recently, the Ministry of Health, Labour and Welfare of Japan introduced a Rehabilitation Performance Index for such wards; this index assesses improvements in the ability to perform ADL, and the results are reflected in medical fees [1]. Older patients with a hip fracture perform ambulatory movements and intensive physical strength training to improve their ability to perform ADL. However, their balance function might not correspond to their expanded ability to perform ADL. Even when older patients with a hip fracture participate in intensive rehabilitation, the number of falls/injured falls is higher than in people without a history of fracture, and a hip fracture of the contralateral side frequently occurs [4, 5]. As such, patients with excessive interest in ADL may reduce their efforts to recover balance function.

There is a relationship between the ability to perform ADL and balance. Matsuyama found a correlation between FIM and TUG performance time of hip fracture patients who were discharged to home from the convalescence rehabilitation wards [21]. Gobbens et al. reported that TUG performance time was associated with ADL and IADL disability in frail community-dwelling older adults [22]. Although participants' total FIM score had almost plateaued, their SIDE level improved further using the BEAR exercises. If excessive attention is paid to ADL, recovery of balance function may be neglected.

A major strength of this study is the addition of exercises using the BEAR for older patients with a hip fracture whose ability to perform ADL had almost plateaued. However, this study had several limitations. First, this study was not a randomized controlled trial (RCT). We compared the treatment group with a historical control group created by propensity score matching. However, the control group did not have data on the total FIM score and the SIDE level at − 4w and baseline. Thus, we cannot exclude the fact that it may not have been the BEAR that improved their function. Second, it focused on older patients with a hip fracture who participated in the convalescent rehabilitation ward in our center, and it was not conducted at multiple sites. Third, the mean of TUG was 17.4 s at post-BEAR. Shumway-Cook et al. reported that 13.5 s or longer was the cutoff level of TUG for identifying community-dwelling adults who are at risk for falls. Thus, participants might need to do more rehabilitation before discharge to recover balance function based on the TUG [16]. In addition, we did not determine the effect of the BEAR exercises to prevent falls and fractures after discharge with long-term follow up.

5 Conclusions

In the BEAR exercises, the rider needed to control the COG using the ankle and hip joints, because the robot moved in accordance with the position of the rider's COG. We found that adding the BEAR exercises to rehabilitation programs could improve balance function more than traditional programs alone, in older patients with hip fracture whose ability to perform ADL had almost plateaued. An RCT is needed to confirm this preliminary data by comparing the effect of BEAR exercises with traditional training. In addition, a long-term, observational study for older adults who experience a hip fracture after discharge is needed to determine whether the BEAR has an effect on fall prevention.

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Author contributions ET: study concept, interpretation of data, statistical analyses, and drafting the article. KO: study concept and design, and recruitment of participants. KS and KK: interpretation of data, critical revision of the article for important intellectual content. MM: critical revision of the article for important intellectual content. IK: study concept and design, statistical advice, and critical revision of the article for important intellectual content.

Compliance with Ethical Standards

Conflict of interest The authors have no conflicts of interest to declare.

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