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Original Article

A Model Used to Consider Lower Extremity Range of Motion to Identify Fall Experience in Community-Dwelling Older Women: A Retrospective Study

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SUMMARY

Background: Reduced lower extremity range of motion (ROM) with aging is related to the frequency of falls in older adults. Therefore, this study developed and assessed a model that considers lower extremity ROM in identifying the frequency of fall in community-dwelling older women.
Methods: Seventy-eight community-dwelling older women (mean age ± SD, 70.4 ± 4.6 years; age range, 65–81 years) were recruited in this study. Nine lower extremity ROMs (hip flexion, hip extension, hip abduction, hip adduction, internal and external hip rotation, knee flexion, ankle dorsiflexion, and ankle plantar flexion) were bilaterally measured. The classification and regression tree methodology was used to develop a model that identifies fall experience for the past 12 months.
Results: Twenty-seven participants reported falling in the past 12 months. The model included left ankle dorsiflexion, left hip flexion, and right hip external rotation ROMs. The area under the receiver operating characteristic curve of this model was 0.710 (95% confidence interval, 0.596–0.825).
Conclusion: The accuracy of the model that considers lower extremity ROMs is moderate for the fall experience in community-dwelling older women.

1. Introduction

Fall is defined as any balance perturbation causing an individual's body to significantly contact the floor or ground.[1] Risk factors for falls in older adults include decreased muscle strength[2] and poor balance ability,[3] which mainly focus on lower extremity functions because most falls occur due to sudden disturbance in balance or stability.[4] Ding and Yang[5] indicated that knee joint muscle strength capacity among older adults who did fall was significantly lower than those who did not fall. Moreira et al.[6] showed that older adults with a fall history presented lower scores in all functional tests examined by the Five Times Sit-to-Stand Test, Timed Up and Go Test, and gait speed. A reduction in the range of motion (ROM) was also related to both decreased muscle strength[7] and poor balance ability.[8]

Regarding reduced ROM with age, there are several changes in joint physiology, including a reduction in the water content of the cartilage and proteoglycans and the volume of synovial fluid.[9] The collagen fibers in the cartilage undergo a cross-linking process, resulting in increased stiffness.[10] These changes may contribute to reduced lower extremity ROM in older adults. A study showed that normal values for all ROMs at the hip joint were 3–5 degrees lower in older adults aged 60–74 years than those in young adults aged 25–39 years.[11] Furthermore, older adults aged 70–92 years showed 13.4%–33.4% of decreases in all motions at the hip with aging.[12]

Hip ROM of older adults should be evaluated given that hip muscles play an important role in regaining balance to help prevent falls.[13] On the other hand, concerning ankle characteristics related to impaired balance,[14] a prospective study[15] on 176 older adults aged 62–96 years reported that reduced ankle dorsiflexion ROM than foot posture at baseline was significantly associated with adults who fell at least once during the last 12-month follow-up. A retrospective study compared hip flexion, knee flexion, ankle dorsiflexion, and ankle plantar flexion ROMs in a group of healthy older individuals with history of falls and a group with no history of falls. As a result, there were significant differences between the two groups with respect to hip flexion and ankle dorsiflexion ROMs, which are 10.0 and 3.3 degrees, respectively.[3] A retrospective study[16] on 372 women aged 40–80 years reported a significant relationship between ankle dorsiflexion ROM and falls. However, to our knowledge, no study has examined the model considering mutual relationships among lower extremity ROMs, including all hip movements, that identifies discriminators for falls in community-dwelling older adults.

Age-related reductions in ROM were approximately 4.9 degrees greater in women than in men.[17] Therefore, this study aimed to develop and examine the accuracy of the model that considers lower extremity ROMs including all hip ROMs (flexion, extension, abduction, adduction, and internal and external hip rotation), knee ROM (flexion), and ankle ROMs (dorsiflexion and plantar flexion) for fall experiences in community-dwelling older women. We hypothesized

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that fall experience can be accurately identified by reduced lower extremity ROMs. These results may be useful in designing intervention programs to reduce and prevent falls in community-dwelling older women.

2. Methods

2.1. Study design and participants

This retrospective study recruited participants via advertisements with the assistance of public learning facilities through various channels, including posters, fliers, and senior newsletters. The eligibility criteria were age ≥ 65 years; living in the community independently; and no serious neurological, musculoskeletal, cognitive, visual, or sensory disorders diagnosed by doctors, affecting the participants' activities of daily living. The convenience sampling method was used to recruit participants from Higashi-Hiroshima City, Hiroshima, Japan, from August 2013 to October 2015. Cohen's description[18] was used to determine the number of samples for the study, considering the calculated sample number (n = 21, in each group) based on the effect size = 0.8, power = 0.8, and α-error = 0.05. The study participants comprised 78 women aged 65–81 (mean ± standard deviation, 70.2 ± 4.5) years. Before testing, the aim and procedures were explained to participants, and all of them provided written informed consent. All procedures performed were in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The ethical committee of the Graduate School of Integrated Arts and Science of Hiroshima University approved this study (ID: 25–26).

2.2. Background variables

Age and medical conditions (cerebrovascular disease, hypertension, osteoporosis, cardiac disease, diabetes, arthritis, pulmonary disease, and cancer) diagnosed by doctors were self-reported. Body height was measured using a vertical standard wall tape. Body weight was measured using a calibrated digital scale.

2.3. Falls ascertainment

Falls data were collected via face-to-face interviews with participants. The investigator explained the definition of falls and encouraged participants to take their time in answering questions to obtain accurate results. Participants were required to describe the falling situation in detail, including whether any falls-related injuries had occurred. Using this procedure, individuals who fell were definitely identified. Then, they were classified as fallers or non-fallers, who fell at least once or did not fall during the past 12 months before ROM measurements, respectively. A history of one or more falls in the past 12 months was a significant discriminator of future falls.[19]

2.4. Lower extremity ROM

Active ROM measurements were selected because older adults' voluntary postural balance maintenance[20] and motor control[1] were associated with falling, while passive ROM measurements do not reflect the voluntary muscle activity at all.[21] ROM was measured using the method specified by Norkin and White.[21] A double-arm (30-cm) stainless steel goniometer (Tsutsumi Corp., Kamagaya City, Chiba, Japan) was used to measure all lower extremity ROMs. The same physical therapist, with 5-year experience of ROM measurements, performed bilateral measurements using the goniometer for all lower extremity ROMs to maximize the consistency of measurement results.[22] The evaluator was blinded regarding group allocation. Before data collection, a pilot study was performed to establish the intrarater reliability of all lower extremity ROM measurements. A test-retest design was used on 15 participants who volunteered for the study, with measurements obtained within 1 week of the original measurements. Intraclass correlation coefficient (ICC) and standard error of measurement (SEM) were used to determine the reliability and precision of all lower extremity ROMs, respectively. An ICC of 0.76–0.99 and a SEM of 1.41–4.71 degrees were considered sufficient for study continuation. Participants were not allowed to perform conventional warm ups because most falls occurred during daily life and not during sports activities, especially at home more than away from home.[23] They were instructed to perform each ROM movement, provided time to rest between ROM measurements, and then resumed when participants reported they were ready to continue. To measure maximum ROMs, participants were instructed to move through full ranges of joint motions without pains, as far as possible, at comfortable speeds by themselves. When participants were familiarized with each ROM movement, ROM measurements were initiated. Table 1 presents ROM measurements. ROM measurements were performed in the following order: supine (hip flexion, abduction, and adduction ROMs), prone (hip extension and knee flexion ROMs); and seated positions (internal and external hip rotation ROMs and ankle dorsiflexion and plantar flexion ROMs).

The evaluator closely observed whether compensatory movements (posterior pelvic tilt or anterior pelvic tilt) occurred or not during measurements; if movements were present, measurements were redone. When a fixed arm of the goniometer had to be placed perpendicular to the floor, the evaluator confirmed the position with his eyes. The positions within the anatomic landmarks required for ROM measurements were confirmed with his hands. The left lower extremity measured at each position were followed by those of the right lower extremity at the same positions. All ROMs were measured twice in degrees, and the best values of right and left sides or each motion, respectively, were used for analysis.

2.5. Statistical analysis

Age, height, weight, BMI, and ROMs between fallers and non-fallers were compared between faller and non-faller. In homogeneous and normally distributed data, independent sample t-tests were used. Mann-Whitney *U*-tests were used whenever normality and homogeneity were not found. Chi-square tests were performed to assess between-group differences in the medical condition. The classification and regression tree (CART) methodology[24] was used to identify the fall experience. If fall occurred in the past 12 months, participants were set at "positive". The CART methodology with the Gini index rule was used as a model to identify the fall experience. The area under the receiver operating characteristic curves (AUCs) were used to evaluate the accuracy of CART methodology. The AUC could distinguish between nonpredictive (AUC < 0.5), less predictive (0.5 < AUC < 0.7), moderately predictive (0.7 < AUC < 0.9), highly predictive (0.9 < AUC < 1), and perfect predictive (AUC = 1) values.[25] Then, sensitivity, specificity, positive likelihood ratio (PLR), and negative likelihood ratio (NLR) were calculated. To assess the validity of the model, cross-validation was performed (i.e., dividing the sample in 10 folds and testing the model developed from the 9 folds on the 10th fold, repeating it for all ten combinations, and averaging the rates of misclassification). The significance level was $p < 0.05$. All data analyses were performed on a personal computer using SPSS (Version 18, SPSS, JAPAN).

Table 1
Explanations of range of motion measurements.

Range of motion	The fulcrum	The fixed arm	The movable arm	Position	Figure
Hip flexion	Centered at the greater trochanter	The lateral midline of the pelvis	The lateral midline of the femur	Supine position	
Hip abduction	The anterior superior iliac spine	The anterior superior iliac spines	The midline of the patella		
Hip adduction			The anterior midline of the femur, while the opposite lower extremity had been abducted to allow adequate space for adduction of the measured lower extremity		
Hip extension	The greater trochanter	The lateral midline of the pelvis, using the lateral epicondyle of the femur as a landmark	The lateral midline of the thigh	Prone position	
Knee flexion	The lateral epicondyle of the femur	The lateral midline of the femur, using the greater trochanter as a reference point	The lateral midline of the fibula, using the lateral malleolus and fibular head as a landmark		
Hip internal hip rotation	The anterior aspect of the patella	Perpendicular to the floor	The anterior midline of the lower leg, using the crest of the tibia and a point midway between the two malleoli for reference	Seated position on a tall chair with the feet off the floor and knee flexed to 90°	
Hip external hip rotation					
Ankle dorsiflexion	The lateral aspect of the lateral malleolus	The lateral midline of the fibula, using the head of the fibula as a reference point	Parallel to the lateral aspect of the fifth metatarsal		
Ankle plantar flexion					

3. Results

Twenty-seven (34.6%) of 78 participants fell at least once during the past 12 months, and 10 (12.8%) reported fall-related injuries, including two fractures, three sprains, and five contusions or cut and graze. However, individuals who had fall-related injuries lived independently in the community when they recruited in this study. No differences in age, height, weight, and medical condition were observed between the groups (Table 2).

ROMs for non-fallers and fallers are shown in Table 3. Fallers exhibited lower right hip extension, right external hip rotation, left external hip rotation, and left ankle dorsiflexion ROMs as compared with non-fallers ($p < 0.05$).

Figure 1 shows the CART model to identify the fall experience in the past 12 months. The number of people who experienced falling was 27 (34.6%), identifying left ankle dorsiflexion (ROM of ≤ 20.5 or > 20.5) as the best single discriminator for fall experience. Among those with ROM ≤ 20.5, the next best discriminator was left hip flexion (ROM of ≤ 130.5 or > 130.5). Among those with ROM ≤ 130.5, the next discriminator was right hip external rotation (ROM of ≤ 30 or > 30). Four terminal nodes were created based on the CART analysis results: rank 1 was the terminal node with the highest probability of fall experience and rank 4 was the terminal node with the lowest probability. Based on AUC, the accuracy of the CART model was 0.710 (95% confidence interval (CI), 0.596–0.825), with an optimal cutoff point of rank 1 (sensitivity = 63%, specificity = 90%, PLR = 6.42, NLR = 0.41). The rates of misclassification were 19% and 28% before and after the cross validation, respectively.

4. Discussion

This study aimed to develop and assess the model considering lower extremity ROM to identify fall experience in community-dwelling older women. Ankle dorsiflexion, hip flexion, and external hip rotation were included in the model, which moderately identifies the fall experience with the AUC above 0.7.

Studies that examined the relationship between lower extremity ROM and falling did not measure all hip ROMs.[3,15,16] Not only knee flexion, ankle dorsiflexion, and ankle plantarflexion ROMs were assessed as in previous studies but also all hip ROMs were measured in this study. Consequently, a model considering lower extremity ROMs to identify fall experience while considering mutual relationships among variables with high contribution ratios were successfully developed. When compared with previous studies that reported reduced ROMs in fallers,[3,15,16] reduced ROMs found in the model developed in this study accurately discriminated fallers among older women. This model may be a useful tool to identify fallers according to ROM perspectives.

Three patterns of postural movements for anterior/posterior sway are ankle, hip, and stepping strategies.[20] The ankle strategy used ankle dorsiflexion ROM as the most commonly used postural movement pattern.[20,26] Ankle dorsiflexion ROM reduction was previously found in fallers.[3,15,16] Furthermore, ankle dorsiflexion ROM was the best discriminator for falls, indicating that ankle dorsiflexion ROM reduction should be considered as the best risk factor for falls in the lower extremity ROM.

Poor one-leg standing balance or smaller hip flexion ROM can distinguish fallers from non-fallers.[3] Smaller hip ROM contributed to older adults' inability to regain balance while falling.[27] Furthermore, reduced hip flexion ROM was the second discriminator for falls in individuals with ankle dorsiflexion ROM reductions in this study, suggesting that hip flexion ROM reductions contributes to falling only under ankle dorsiflexion ROM reductions.

An interesting observation was reduced external hip rotation ROM as the third discriminator in fallers with reduced ankle dorsiflexion and hip flexion ROMs. To our knowledge, this is a novel finding. Reduced external hip rotation ROM is affected by hip retrotorsion or shortened piriformis muscle,[28] related to poor control of pelvic motion during walking,[29] found in fallers,[30] and is associated with slow walking velocity,[31] a significant characteristic of fallers.[30] These may be related to falling which occurs during walking.

The personal reaction time of the left leg was always longer than that of the right leg, irrespective of leg dominance,[32] explaining why reduced left lower extremity ROMs are considered as risk factors for falls. Most studies did not investigate how reduced ROMs on the left and right sides were related to falling. Reduced ROM on

Table 2
Baseline characteristics in non-fallers and fallers.

Characteristic	Non-fallers (n = 51)	Fallers (n = 27)	p value
Age, years (mean ± SD)	70.7 ± 4.6	69.4 ± 4.4	0.184[a]
Height, cm (mean ± SD)	152.3 ± 4.8	153.9 ± 4.6	0.152
Weight, kg (mean ± SD)	52.8 ± 5.7	54.6 ± 7.8	0.440[a]
BMI	22.8 ± 2.3	23.1 ± 3.2	0.661
Medical condition, n (%)			
Cerebrovascular disease	3 (5.9)	1 (3.7)	0.678
Hypertension	14 (27.5)	8 (29.6)	0.839
Osteoporosis	7 (13.7)	7 (25.9)	0.182
Cardiac disease	2 (3.9)	4 (15.4)	0.076
Diabetes	6 (11.8)	3 (11.1)	0.932
Arthritis	16 (31.4)	9 (33.3)	0.860
Pulmonary disease	1 (2.0)	0 (0.0)	0.464
Cancer	3 (5.9)	5 (18.5)	0.080

[a] The Mann-Whitney U test.

Table 3
Range of motion in non-fallers and fallers.

Variables	Non-fallers (n = 51)	Fallers (n = 27)	p value
Hip flexion			
Lt	126.5 ± 7.4	122.7 ± 6.9	0.071[a]
Rt	124.8 ± 7.6	121.4 ± 7.4	0.066
Hip extension			
Lt	17.7 ± 4.3	16.6 ± 4.9	0.321
Rt	17.6 ± 4.1	15.1 ± 5.3	0.022
Hip abduction			
Lt	34.7 ± 6.0	36.1 ± 5.4	0.306
Rt	32.8 ± 5.9	34.3 ± 7.4	0.340
Hip adduction			
Lt	19.3 ± 3.7	19.0 ± 2.8	0.767[a]
Rt	18.8 ± 3.8	17.8 ± 4.1	0.251
Internal hip rotation			
Lt	30.1 ± 6.8	28.8 ± 7.9	0.456
Rt	27.7 ± 7.1	26.3 ± 6.7	0.390
External hip rotation			
Lt	28.1 ± 7.0	24.7 ± 6.7	0.038
Rt	31.0 ± 5.2	28.3 ± 5.3	0.037
Knee flexion			
Lt	127.1 ± 8.1	129.0 ± 7.2	0.328
Rt	127.7 ± 8.3	128.7 ± 7.2	0.600
Ankle dorsiflexion			
Lt	19.2 ± 5.7	15.6 ± 5.7	0.008
Rt	19.0 ± 6.3	16.0 ± 7.3	0.057
Ankle plantar flexion			
Lt	61.2 ± 7.0	59.4 ± 6.9	0.300
Rt	60.4 ± 6.0	58.7 ± 7.5	0.304

Note: Values are mean ± SD of range of motion (in degrees).
[a] The Mann-Whitney U test.
Lt: left; Rt: right.

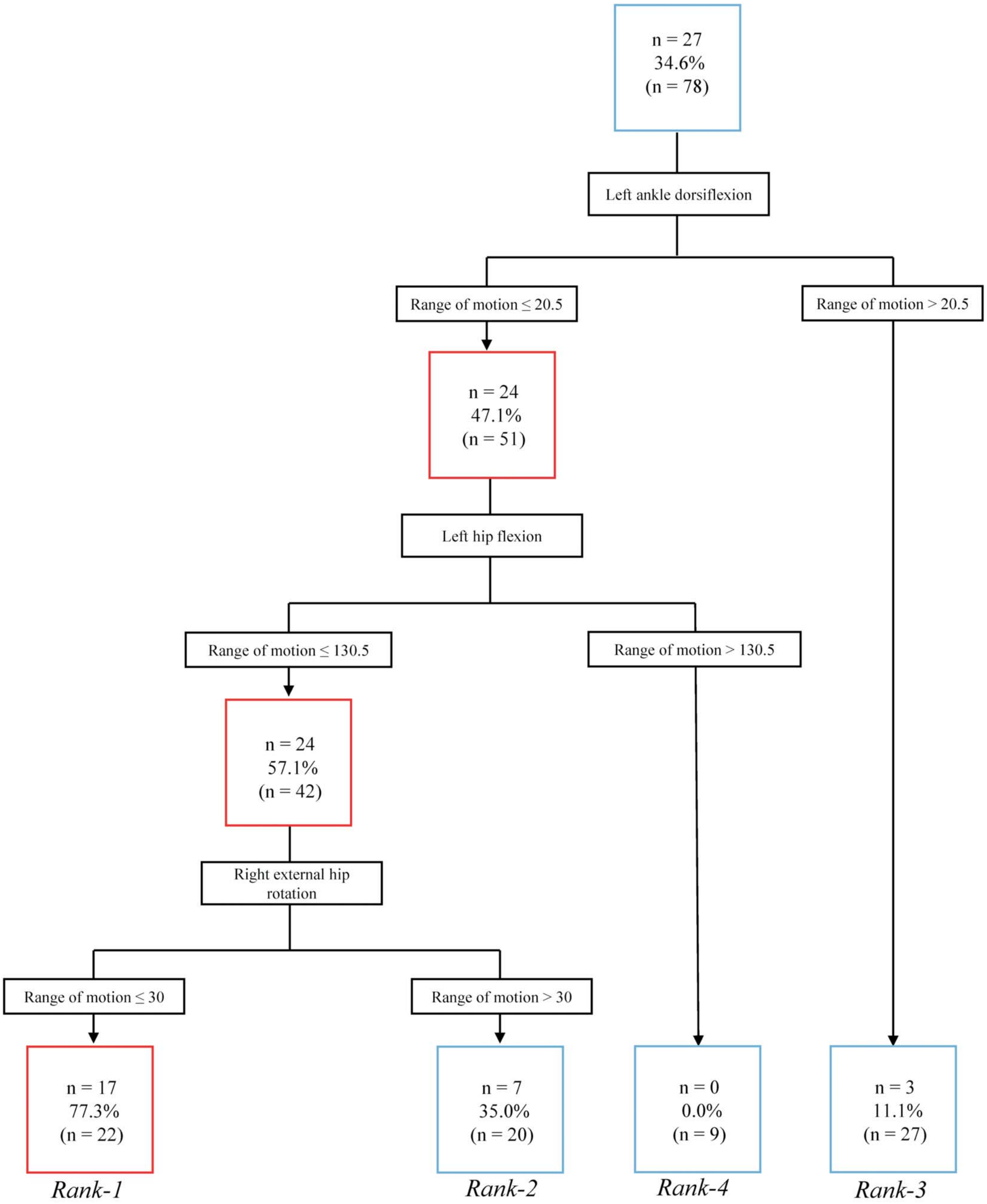

Figure 1. The CART model to identify the presence of fall experience. For each category, the top statistic is the number of participants who have fall experience, and the middle number is the percentage of fallers in each group.

the left side more associated with fall occurrence than that on the right side, suggesting that future intervention studies to prevent falls should target ROM on the left side than on the right side.

Regarding ROMs included in this model, a cutoff value of 20.5° for ankle dorsiflexion as a best discriminator is similar to 20.0° of that reported as a normative value in the American Academy of Orthopaedic Surgeons (AAOS).[33] Conversely, a cutoff value of 130.5° for hip flexion as a second discriminator is higher than 120.0° reported by the AAOS. However, a cutoff value of 30.5° for external hip rotation ROM as a final discriminator is much lower than 45.0° for that of the AAOS. These results strongly suggest that although reduced ankle dorsiflexion ROM is observed in older women, reduced other hip ROMs should also be carefully evaluated for the risk of falling.

This study had several limitations. First, we did not investigate the dominant leg in participants. Therefore, we cannot provide information about the dominant leg related to falling. Second, ROM measurements were performed in the same order. Thus, tissue properties may not be the same in between the first and last measurements, indicating a possible bias in the measurement results. Third, potential compensatory movements (posterior pelvic tilt or anterior pelvic tilt) may be accompanied during measurements, possibly affecting the accuracy of ROM measurements. Furthermore, knee flexion ROM measurements may not be accurately performed because the hamstrings deactivate when the knee is fixed more than 90 degrees. These may be related to the method of active ROM measurement. Nevertheless, previous studies have selected active ROM measurements[10,11] and have shown consistent results with those from passive ROM regarding reduction with age.[11] Therefore, active ROM measurements performed in this study are available in the model to identify fall experience. Fourth, our study had a small sample size. It may not be enough to perform CART analysis, which has been designed to deal with large data sets. However, the model developed by CART analysis showed moderate levels of accuracy. Thus, the risk of sampling bias may not be serious. Fifth, we did not clarify the influence of medical conditions on the relationship between reduced ROM and fall experience. In this study, medical conditions were not different between fallers and non-fallers. However, it is reported that reduction of ROM associated with musculoskeletal disorders such as arthritis and osteoporosis.[34] Further prospective studies are warranted to investigate how the progression of musculoskeletal disorders and loss of ROM with age are associated with falling. Furthermore, passive ROM should be included, possibly contributing to improving AUC results. In the study for frail older adults, mental disorders, such as dementia, would be generally considered into their analysis for falling.[35] Sixth, data on falls may be limited by participants' ability to retrospectively remember such events; thus, recall bias is inevitable. Moreover, we did not investigate when falls occurred. Depending on when a fall or a fall-related injury occurs, ROM may be affected. Finally, this was a retrospective study. Therefore, it could not establish a causal relationship between reduced lower extremity ROMs and fall occurrence. Additionally, the level of evidence obtained from this study would be weak. However, the findings of this study can be the basis for quantitatively supporting the validity of unproven clinical judgment. Despite these limitations, considering that history of falls can be used to predict future falls,[19] based on the results from older women with fall experience, further interventions focusing on lower extremity ROMs may contribute to help prevent and reduce falls among older women.

5. Conclusions

The model considering lower extremity ROM moderately predicts fall experience in community-dwelling older women. This study found significant factors that may prove useful in a clinical setting to maximize the potential benefit of interventions aimed at reducing and preventing falls.

Conflicts of interest

None.

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