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Fall prediction using decision tree analysis in acute care units

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Abstract. [Purpose] To present an accurate and straight-forward system of fall prediction by performing decision tree analysis using both the fall assessment sheet and Berg balance scale (BBS). [Participants and Methods] The participants in this retrospective study were inpatients from acute care units. We extracted the risk factors for falls from the fall assessment and performed a decision tree analysis using the extracted fall risk factors and BBS score. [Results] "History of more than one fall in the last 1 year", "Muscle weakness", "Use of a walking aid or wheelchair", "Requires assistance for transfer", "Use of Narcotics", "Dangerous behavior", and "High degree of self-reliance" were fall risk factors. The decision tree analysis extracted five fall risk factors, with an area under the curve of 0.7919. Patients with no history of falls and who did not require assistance for transfer or those with a BBS score ≥51 did not fall. [Conclusion] Decision tree-based fall prediction was useful and straightforward and revealed that patients with no history of falling and those who did not require assistance for transfer or had a BBS score ≥51 had a low risk of falling.

Key words: Falling, Balance, Decision tree

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INTRODUCTION

Fall injury is the most frequently reported event in acute care units[1]. About 1–10% of falls reportedly cause severe trauma and life-threatening problems[2]. Falls can also result in psychological problems, such as fearfulness[3] and loss of confidence[4].

Many studies on fall factors and fall risk prediction have been reported since 1980, and multifaceted fall risk assessments have been developed. Among these fall risk assessments, St. Thomas's Risk Assessment Tool in falling elderly inpatients (STRATIFY)[5] and the Morse Fall Scale (MFS)[6] are considered to meet the criteria for gold-standard risk assessment tools. The Japan Nursing Association has recommended the use of a "fall assessment sheet" since 1999 to predict fall risk, and the revised one for each facility used it[7]. The fall assessment sheet of Fujioka General hospital assesses 39 items, including age, fall history, sensory disorders, motor dysfunction, activity, cognitive function, drugs being used, excretion, physical symptoms, use of nurse calls, and patient characteristics.

In rehabilitation, the Berg Balance scale (BBS) is used to evaluate the risk of falls. The BBS is reliable and valid[8, 9], and is in frequently used[10, 11]. However, the BBS shows a drawback in that it cannot evaluate the influence of other factors, because it only assesses balance function. Causes of falls can be broadly categorized into environmental and patient factors[12], with the combination of these factors increasing the risk of falls[13]. Reported patient factors include the fall history, nervous-

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ness, confusion, disorientation, weakness, gait instability, urinary incontinence, visual impairment, and use of certain drugs (hypnotics, analgesics, vasodilators, diuretics and antidepressants)[14–16].

In a previous study on the prediction of falls, faller characteristics were extracted from a report on patients who had fallen and the number of risks items was evaluated[5]. In some cases, logistic regression analysis was performed on the extracted factors, weighted for each item scored and cutoff values were determined using receiver operating characteristic (ROC) curves[17]. Some studies have used both a test of balance function and an assessment of fall risk factors[18], but those studies treated risk factors as independent factors, not as multiple relevant factors. How multiple factors are interrelated to cause falls thus remains unclear.

Decision tree analysis is a data-mining technique that can be used regardless of the scale of explanatory variables, and subdivides successive cases into independent groups based on the values of the independent variables, finally dividing them into several groups. The tree diagram is hierarchized in descending order of relationship, to facilitate the understanding of interrelationships between factors. Deschamps used decision tree analysis to make fall predictions for community-dwelling elderly individuals with no history of falls[19]. That study indicated that decision trees are useful for predict falls.

However, no reports in the literature have described falls prediction using decision tree analysis for inpatients. Previous studies have reported several falls risk factors for inpatients, but none have revealed the links between elements. In addition, no studies have described fall prediction using both the BBS and factors other than balance function. The purpose of this study was thus to present an accurate and straightforward method of fall prediction by performing decision tree analysis using both the fall assessment sheet and the BBS.

PARTICIPANTS AND METHODS

Our hospital has 399 beds, 322 of which are acute care wards. Electronic medical records and incident/accident reports were used for data collection. The incident/accident report is a system that reports the occurrence status of falls or other adverse events and the degree of subsequent impact on the patient. This study was a retrospective study conducted at a single institution.

In this study, participants in the first extraction of fall risk factors were all patients ≥20 years old admitted to acute care units between April and September 2018. Decision tree analysis was then performed using the extracted factors and BBS. The extraction of fall risk factors was conducted in a retrospective longitudinal study (1,309 patients; mean age, 70.4 ± 17.0 years). Patients for whom all required assessments were completed during the hospital stay were included in this study. Items for collection included necessary information (age and medical department), the fall assessment sheet, and the presence or absence of any falls before leaving the acute care units. For patients with multiple falls, information up to the time of the first fall was collected. Moreover, for patients who had been hospitalized more than once during the study period, information on each hospitalization was collected. This study did not include any patients who were hospitalized more than once and experienced multiple falls. The analysis used all fall assessment information during the study period up to the time of the first fall. Data from any case in which a fall occurred after the fall assessment evaluation were defined as faller data. Furthermore, data from cases in which no falls occurred after the fall assessment evaluation were defined as non-faller data.

Decision tree analysis was performed in a retrospective cross-sectional study. Study inclusion criteria were: age ≥20 years; and evaluation of the BBS (86 patients; mean age, 75.0 ± 12.1 years). This analysis included patients who overlapped with participants for the extraction of fall risk factors from the fall assessment sheet. Exclusion criteria were: missing records for the BBS score or fall risk assessment. Fall assessment was evaluated on day 1 of hospitalization, on day 2 or 3, on day 7, and weekly thereafter. This analysis therefore used the fall risk assessment closest to the date of BBS evaluation. We also confirmed whether the patient had experienced a fall after the fall assessment and BBS had been performed, but before discharge from the acute care units.

The fall assessment sheet of Fujioka General Hospital used for analysis in this study comprises 39 items, yielding a total of 46 points (Table 1). When scoring, a score was given for the presence of one or more characteristics within those characteristics given the same score under each risk item. For example, in the “Sensory” risk item, a positive result for “visual impairment” or “hearing impairment” or both yields the same score of 1 point. Patients were then classified into risk categories: risk I, 1–9 points; risk II, 10–19 points; and risk III, ≥20 points. Ward nurses performed this evaluation on day 1 of hospitalization, day 2 or 3 after admission, day 7, and weekly thereafter. A nursing care plan is prepared for patients with a risk category ≥II to prevent falls.

The BBS comprises 14 items for movements in daily life, for a total of 56 points. Measurement is possible without using special equipment. Both inter- and intra-rater reliabilities were very high, and cutoff values are also shown[8].

In the analysis to extract fall risk factors, the relationships between in-hospital falls and all endpoints were analyzed using the χ^2 test. Logistic regression analysis was performed using backward elimination with significant items as independent variables, and the occurrence of falls as the dependent variable. Decision tree analysis was performed on the extracted fall risk factors and BBS using the presence or absence of the occurrence of falls, the dependent variable, and the total score of the extracted fall risk factors and BBS as independent variables.

The decision tree represents an algorithm for determining a class classification corresponding to an input pattern using a tree structure. The divergence criterion in the analysis depends on the dependent variable. For continuous variables, the

Table 1. Fall risk assessment used at Fujioka General Hospital and characteristics of patients who sustained a fall and those who did not

Risk item	Characteristic	Score	Non-fallers (n=3,598)	Fallers (n=61)	p
Age	≥70 years	2	67.60%	83.60%	0.008*
Fall history	More than 1 fall in the last year	2	23.50%	44.30%	<0.001*
Sensory	Visual impairment	1	22.30%	19.70%	0.756
	Hearing impairment		13.50%	8.20%	0.341
Motor function	Muscle weakness	3	43.50%	65.60%	0.001*
	Paralysis	2	13.50%	19.70%	0.184
	Numbness		3.60%	3.30%	1
	Bone/joint problems (contracture/deformation)		5.60%	3.30%	0.774
Mobility	Loss of balance	3	12.30%	16.40%	0.326
	Use of a walking aid or wheelchair	2	27.60%	42.60%	0.029*
	Free gait		30.90%	19.70%	0.068
	Small steppage gait Intermittent claudication gait		0.90%	1.60%	0.427
	Requires assistance for transfer	1	49.00%	27.90%	0.001*
Cognition	Dementia	4	16.70%	21.30%	0.386
	Night delirium		2.60%	8.20%	0.024*
	Disorientation Unconsciousness/confusion		10.20%	14.80%	0.282
	Impaired understanding/judgment/memory		19.30%	60.70%	<0.001*
Medicine	Temporary use of hypnotics/tranquilizers	4	3.50%	3.30%	1
	Narcotics	2	4.40%	11.50%	0.019*
	Painkillers	1	23.50%	27.90%	0.447
	Diuretics		8.50%	4.90%	0.483
	Antihypertensives/diuretics		29.80%	26.20%	0.672
Excretion	Frequent urination	3	10.70%	6.60%	0.402
	Toileting at night		29.20%	26.20%	0.672
	Urinary/fecal incontinence	2	26.30%	32.80%	0.244
	Use of a commode chair	1	17.50%	24.60%	0.173
	Use of a urinal		3.60%	6.60%	0.285
	Use of a wheelchair toilet		4.70%	6.60%	0.532
	Requires assistance for excretion		34.90%	45.90%	0.079
Condition	Body temperature ≥38°C	2	21.20%	24.60%	0.528
	Frequent dizziness		3.40%	1.60%	0.723
	Rehabilitation		11.40%	14.80%	0.414
	Change in condition/ADL		45.50%	55.70%	0.121
Nurse call	Act without calling	4	12.20%	23.00%	0.018*
	Unable to use call Cannot recognize call		12.30%	21.30%	0.047*
Personality	Dangerous behavior	3	5.30%	19.70%	<0.001*
	High degree of self-reliance		2.10%	11.50%	<0.001*
	Not accustomed to changes in environment	1	44.20%	34.40%	0.129

*p<0.05.

sum of squares (SS) of the variance analysis factor is used. For categorical variables, the item with the branch showing the largest likelihood ratio Gini coefficient (G2) is used. In this study, since the dependent variable was the presence or absence of the occurrence of falls, representing a categorical variable, the latter branching criterion was adopted. The best branch was advanced interactively, and ended when five terminal nodes could not branch any further. The ability to predict the outcome of falling from the decision tree model was assessed as the area under the receiver operating characteristic curve (AUC).

For all statistical analyses, IBM SPSS Statistics version 25 (IBM Corp, Armonk, NY, USA) and JMP Pro version 14 (SAS

Institute Inc., Cary, NC, USA) were used, with a significance level of 5%.

Because this was a retrospective observational study and used only existing data, no written or oral consent was obtained from subjects. Opt-out options for the study information of subjects were posted on the hospital bulletin board and on the hospital website), providing an opportunity to refuse participation. This study was approved by the Ethics Review Committee of Fujioka General Hospital (approval number 131) and was conducted in compliance with the Declaration of Helsinki.

RESULTS

A breakdown of participants included in the extraction of risk factors for falls is shown in Table 2. The total number of hospitalized patients ≥20 years old during the study period was 2,031. No fall assessment scores were missing, and 1,309 patients were analyzed in 3,659 assessments. Mean hospital stay was 12.7 ± 13.0 days, and mean number of assessments performed per patient was 2.8.

Table 1 shows the number of sub-items in the fall assessment sheet of this hospital based on the presence or absence of the occurrence of falls and results from univariate analysis using χ^2 test. Table 3 shows the results of logistic regression analysis using 12 items showing significant differences as independent variables and the presence or absence of the occurrence of falls as a dependent variable. Factors associated with falls were: "History of more than 1 fall in the last 1 year", "Muscle weakness", "Use of a walking aid or wheelchair", "Requires assistance for transfer", "Use of narcotics", "Dangerous behavior", and "High degree of self-reliance".

A breakdown of participants included in the decision tree analysis of extracted fall risk factors and BBS is shown in Table 4. Among the 86 participants, there was no loss of data. Mean hospital stay was 21.5 ± 17.4 days, and 13 people experienced falls. Mean numbers of days from admission to fall assessment and BBS were 16.2 ± 15.3 days and 16.7 ± 15.6 days, respectively. Table 5 shows the number of fall risk factors in subjects depending on the presence or absence of the occurrence of falls, and Fig. 1 shows the results of decision tree analysis for predicting falls.

First, history of falls within the preceding year caused a divergence. Then, regardless of the history of falls, another divergence was seen for assistance with transfers. Patients who had no history of falling and did not require assistance with transfers experienced no falls during the study period. Patients who had no history of falling, but required assistance for transfer diverged at a BBS of 51 points, with patients showing BBS ≥51 patients did not experience fall, while those with

Table 2. Number and clinical departments of the participants

Clinical departments	Number of hospitalized patients	Number of participants	Age, mean (SD)
Internal medicine	807	502	74.6 (14.4)
Surgery	362	249	69.9 (13.1)
Orthopedic surgery	249	149	70.9 (18.3)
Neurosurgery	200	116	73.3 (14.5)
Obstetrics/gynecology	118	82	38.8 (15.9)
Urology	131	90	74.2 (10.7)
Hematology	96	69	69.1 (10.8)
Emergency	35	31	63.6 (27.1)
Ophthalmology	25	17	75.2 (8.5)
Dermatology	5	3	85.0 (2.6)
Dental surgery	3	1	88.0
Total	2,031	1,309	70.4 (17.0)

Table 3. The results of the logistic regression analysis for the fall risk assessment

Risk item	B	p	Exp (B)	95% CI
More than 1 fall in the last year	0.601	0.028*	1.823	1.066–3.117
Muscle weakness	0.485	0.09*	1.624	0.928–2.843
Use of a walking aid or wheelchair	0.549	0.044*	1.731	1.014–2.955
Requires assistance assist for transfer	0.630	0.039*	1.878	1.033–3.413
Narcotic	1.136	0.007*	3.113	1.363–7.112
Dangerous behavior	0.889	0.014*	2.434	1.195–4.959
High degree of self-reliance	1.029	0.025*	2.799	1.135–6.902

95% CI: 95% confidence interval. *p<0.05.

BBS <51 experienced a higher rate of falls. Three of the patients who had a history of falling but did not require assistance for transfer subsequently experienced falls. Patients who had a history of falling and needed assistance for transfer then diverged again for high degree of self-reliance, with only one patient with a high degree of self-reliance experiencing a fall.

Table 4. Results of clinical evaluation of patients for whom BBS was evaluated in each department

	n	Fallers	Age (years)	Length of hospital stay (days), mean (SD)	BBS Score, mean (SD)	Days to evaluate, mean (SD)	
						Fall risk assesument	BBS
Internal medicine	22	2	78.5 (10.3)	26.1 (21.5)	46.6 (5.5)	17.5 (17.4)	18.4 (18.3)
Surgery	7	1	83.4 (6.2)	48.6 (17.9)	43.0 (5.9)	40.1 (18.2)	41.85 (17.6)
Neurosurgery	42	7	73.2 (12.1)	14.6 (9.8)	46.4 (8.8)	10.9 (10.2)	11.2 (10.0)
Orthopedic surgery	15	3	70.8 (13.8)	21.2 (13.7)	47.4 (7.1)	17.7 (11.8)	17.7 (11.6)
Total	86	13	75.0 (12.1)	21.5 (17.4)	46.3 (7.5)	16.2 (15.3)	16.7 (15.6)

Table 5. Fall risk factors in patients for whom BBS was evaluated

Risk item	Characteristic	Non-fallers (n=73) Applicable rate (%)	Fallers (n=13) Applicable rate (%)
Fall history	More than 1 fall in the last year	38.4%	69.2%
Motor function	Muscle weakness	50.6%	69.2%
Mobility	Use of a walking aid or wheelchair	34.9%	38.5%
	Requires assistance for transfer	48.2%	76.9%
Medicine	Narcotics	0.0%	0.0%
Personality	Dangerous behavior	3.6%	7.7%
	High degree of self-reliance	12.0%	23.1%

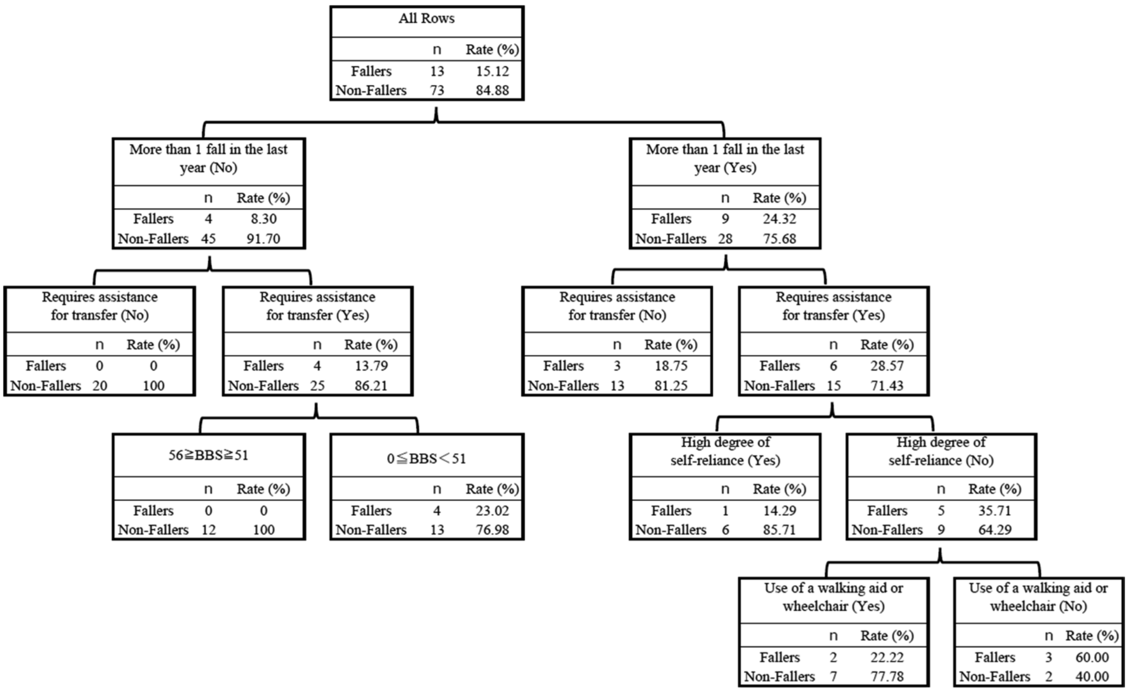

Fig. 1. Results of decision tree analysis using extracted fall risk factors and BBS.
At each divergence, the split to the left shows the lower fall risk, and the split to the right shows the higher fall risk. Area under the receiver operating characteristic curve (AUC) for the decision tree model is 0.7919.

Patients with a low degree of self-reliance finally diverged again according to the use of wheelchairs and walking aids. Two patients (40%) fell when using these assistive devices, and three (60%) fell when not using them. AUC for the decision tree model was 0.7919.

DISCUSSION

The incidence of falls at our hospital was 4.7%. In a report from an acute care hospital in Japan, Nasuhara et al.[20] described an incidence of 7.5% and Dan et al.[21] reported an incidence of 1.6%. From the results of logistic regression analysis, "Fall history", "Muscle weakness", "History of more than 1 fall in the last 1 year", "Use of a walking aid or wheelchair", "Requires assistance for transfer", "Use of narcotics", "Dangerous behavior", and "High degree of self-reliance" were extracted as fall risk factors. Age was not a significant factor, but this was considered to be because all subjects were older, regardless of whether they had fallen. Among the extracted factors, both STRATIFY and MFS include fall history, use of wheelchair/walking aids, requires assistance for transfer, and dangerous behavior. Muscle weakness is a risk factor for both acute care hospitals and long-term care hospitals[17, 22]. Muscle weakness was also extracted in the present study, and was considered a risk factor throughout the acute to chronic phases. Drug use has also been included in domestic and foreign evaluations, but narcotics in particular were highly evaluated, especially in Japan, and have been considered an essential fall factor for consideration in hospitalized patients[23]. High degree of self-reliance has also been reported as a fall factor[24, 25]. The factors extracted in this study were thus considered appropriate for acute units.

Thirteen of the 86 patients experienced a fall, showing more falls than the patient cohort from which fall risks were extracted. The mean BBS score of patients included in the decision tree analysis was 46.3, under the cutoff value of 48 described by Harada et al[26]. Therefore, many falls were thought to have occurred.

The decision tree first diverged according to the history of falls, then by the requirement for assistance for transfer, regardless of whether a history of falls was present. No subsequent falls were seen in patients who did not require assistance for transfer. Whether to assist in a transfer is determined by the nurse, and Eagel et al.[27] reported that clinical judgment of the risk of falls by nurses offered similar prediction accuracy to the MFS and Functional Reach Test. Therefore, it was considered that there were no falls for patients that nurses judged to be at low risk of falls. Patients who had not fallen and required assistance for transfer showed divergence for BBS scores. Among patients with no history of falls, those requiring assistance for transfer and having a BBS score ≥51 did not experience subsequent falls. The mean age of study participants was 75 years, and patients with a BBS ≥51 did not experience falls. This is consistent with reports that 75-year-olds should show a balance of BBS ≥51.14[28]. However, the result is that patients with BBS ≥51 may still need assistance in transfer. This is similar to a report that the clinical judgment of nurses regarding fall risk is of low specificity[29]. To prevent falls and the need for excessive care, evaluation of BBS in conjunction with past history of falls appears important.

Patients who have a history of falling and need assistance for transfer next show divergence, according to their degree of independence. Tables 1, 5 a higher proportion of fallers exhibited a high degree of self-reliance than non-fallers, but decision tree analysis showed that the risk of falling was lower for those patients who were more independent. Patients with a high degree of self-reliance may thus have been classified as fallers due to other factors before diverging by degree of independence. Patients with weak independence then diverged according to whether they used walking aids or wheelchairs, with those not using such devices showing a higher fall incidence. Elderly individuals with a poor perception of physical function have been reported to be at increased risk of falling[30]. Patients who regularly use walking aids or wheelchairs would conceivably be at lower falling risk because they have a better grasp of the limits of their abilities. Also, falls have generally been reported to occur during transfers in the patient's room[31, 32]. Therefore, practice transferring from the bed to the wheelchair and adjusting the environment around the bed might be considered essential.

In this study limitation, regardless of whether rehabilitation was performed, fall risk factors were extracted for inpatients in the acute care units, where subjects were frequently internal medicine and surgical patients. However, in the decision tree analysis of fall risk factors and BBS, neurosurgical patients were the most common, and patients who were using drugs were not included. Therefore, the decision tree in this study may not have been optimal for patients taking narcotics. Also, in this study, prediction accuracy in different populations was not able to be verified using the created decision tree. In the future, BBS will need to be measured for all patients regularly, BBS analyzed and fall assessments conducted longitudinally.

In conclusion, according to the results of this study, patients hospitalized in the acute care units showed "Fall history", "Muscle weakness", "History of more than 1 fall in the last 1 year", "Use of a walking aid or wheelchair", "Requires assistance for transfer", "Use of narcotics", "Dangerous behavior", and "High degree of self-reliance" as risk factors for falls. Decision tree-based fall prediction appears useful and straightforward, and revealed that patients with no history of falls and no requirement for assistance with transfer or who had a BBS score ≥51 had a low probability of falling. Patients who have a history of falling and need assistance for transfer need to attain a high degree of self-reliance and to perform transfer practice and sufficient modification of the environment.

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Conflict of interest

None.

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