

New Predictive Models for Falls in Acute Care Setting Classified Using An Activities of Daily Living Scale in Japan: A Retrospective Cohort Study

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Abstract

Background

In several current fall prediction models, the reported predictors vary from one model to another. We developed and validated a new fall prediction model for patients admitted to an acute care hospital by identifying predictors of falls considering a combination of background factors and one crucial stratum.

Methods

We conducted a retrospective cohort study of patients admitted to Shizuoka General Hospital from April 2019 to September 2020, aged 20 years or older. We developed and validated a new fall prediction model by identifying predictors of falls stratified by essential activities of daily living (ADL) indicators and integrating these models.

Results

A total of 22,988 individuals were included in the analysis, with 653 (2.8 %) experiencing all falls and 400 (1.7 %) experiencing falls with medical resources during the study period. Multivariate analysis was performed after one stratification level, using bedridden rank (ability to move around in daily life) as a stratifying variable, a clinically important variable and highly correlated with 17 other variables. The results of multivariate analysis showed that the risk factors for falls (high risk) were age (high), sex (men), and ambulance transport (yes) for rank J (independence/autonomy); age (high), and sex (men) for rank A (house-bound); There were no predictors for rank B (chair-bound); and there was ophthalmologic disease (no) for rank C (bed-bound). The c-index indicating the prediction model's performance for falls within 28 days of hospitalisation was 0.705 (95 % CI, 0.664–0.746). Hosmer-Lemeshow goodness-of-fit statistics were significant ($\chi^2 = 192.06$; 8 degrees of freedom; $p < 0.001$). The c-index for the entire unstratified sample was 0.703 (95 % CI, 0.661–0.746), indicating that the predictive model stratified by bedriddenness rank was accurate ($p < 0.001$).

Conclusion

We identified predictors of falls using important ADLs (bedriddenness rank) and developed a more accurate prediction model in acute care hospital settings. This predictive model is an essential tool for fall prevention.

Background

In 2019, the proportion of the population aged 65 years or older in Japan reached a record high of 28.4 % [1]. Furthermore, a survey by the Ministry of Health, Labour and Welfare (MHLW) in 2017 revealed patients aged 75 years or older accounted for 41.5 % of the total number of patients admitted to acute care hospitals [2]. Therefore, it is expected that the number of older adult patients with a high risk of falling will further increase in the future. Additionally, although not limited to the elderly, falls in hospitalised patients can cause physical injuries and secondary complications, leading to a decline in activities of daily living (ADL) and sometimes even death. Therefore, fall prevention has become an important issue to protect patients' quality of life (QOL) and lives [3].

Interventions for fall prevention measures need to be conducted in a high-risk patient population that is likely to fall at the time of admission. Further, a fall prediction model needs to be constructed to identify these high-risk patients. Several such fall prediction models have been reported [4–7]. The STRATIFY scale [5] lists the history of falls, visual impairment, mental status, frequency of elimination, and ability to transfer and move as factors (predictors) to construct a prediction model. The Morse Fall Scale [6] includes six items related to the history of falls, comorbidities, use of walking aids, intravenous fluids, ability to walk and move, and mental status. The Medication Fall Risk Score and Evaluation Tool [7] assesses medication-related fall risk. It lists all medications that patients take as predictors according to risk level (high risk: analgesics, antipsychotics, anticonvulsants, benzodiazepines; medium risk: antihypertensive, cardiac, antiarrhythmic, antidepressants; low risk: diuretics). In particular, Tago et al. [4] reported seven predictors of falls in Japan: sex, emergency hospitalisation, admission to neurosurgery, use of sleeping pills, history of falls, independence in eating, and level of independence in daily living (bedriddenness rank) in people with disabilities. In Japan, most hospitals use assessment tools to predict falls, but the reported predictors of each of the above models are situational.

In Japan, there are facilities called Diagnosis Procedure Combination (DPC) [8, 9] hospitals that specialise in acute inpatient care. These facilities are required to deal with clinical issues such as enhanced acceptance of emergency patients, shortening of the average length of stay, maintenance of bed occupancy, and early reacquisition of ADLs. As of April 2020, 1,757 DPC hospitals such as the Shizuoka General Hospital, which is the field of this study, are classified into 82 university main hospital groups. Further, 156 DPC specific hospital groups and 1,519 DPC standard hospital groups are classified according to each facility's medical level. Furthermore, the classification will be based on the characteristics and severity of the diseases of the hospitalised patients [8].

Moreover, most of the reported fall prediction models have been constructed using linear regression models. No attempts have been made to improve prediction accuracy by considering interaction terms and stratifying critical prognostic factors, such as regression tree analysis and random forests.

Against this background, we developed and validated a new fall prediction model for patients admitted to an acute care hospital (DPC hospital) in Japan by identifying predictors of falls stratified by important ADL indicators (bedriddenness rank) and integrating these models.

Methods

Participants and study design

This was a retrospective cohort study of patients aged ≥ 20 years admitted to Shizuoka General Hospital from April 2019 to September 2020. We excluded inpatients with inpatient dental surgery, inpatients with obstetrics and gynaecology during pregnancy, childbirth, puerperium, and inpatients with unknown bedridden status, which are not subject to DPC (Figure 1).

Variables at hospitalisation

Variables were age, sex, height, weight, body mass index (BMI), emergency admission [4], ambulance transport, history of dementia, Parkinson's disease, stroke, and visual impairment (diagnosis of glaucoma or cataract) [5], use of care insurance, presence of cognitive function scores, inpatient ward (internal medicine, department of surgery, or emergency department) [4], disturbance of consciousness. Additionally, the variables for ADLs [4] were eating [4], transferring [5,6], dressing, moving and using the toilet, bathing, walking on the level ground [6], stair climbing, changing clothes, defecation management, and urination management [5]. Furthermore, there were good sleep condition, use of sleeping pills [4], medication management status (myself or others), fall assessment items at admission (history of falls within one year [4–6]), inability to stand without holding, impaired judgment and comprehension, and toileting assistance, and use of portable toilet, and level of independence in the daily life of an individual with disabilities (bedriddenness rank).

The Japanese MHLW bedriddenness rank

Bedriddenness rank [10, 11] by the Ministry of Health, Labor, and Welfare is an official assessment tool in Japan's long-term care insurance system that evaluates the degree to which a person's daily life is limited. The degree of bedriddenness can be easily assessed by monitoring the person's movements in everyday life, such as whether the patient is independent, in a wheelchair, or bed. Further, it is ranked into four levels, with particular attention to the state of mobility rather than ability. As for the degree of bedriddenness by rank, rank J is defined as independence/autonomy, rank A as house-bound, rank B as chair-bound, and rank C as bed-bound. We ranked the degree of bedriddenness based on evaluation by medical personnel and reports from family members. The detailed evaluation procedure and its reliability have already been reported by Tago et al. [4, 11]. Bedriddenness. Thus, the bedriddenness rank is easy to evaluate and is commonly used in Japan's medical and nursing care settings.

Falls within 28 days of hospitalisation as an outcome

The primary outcome was the time from admission to the date of a fall incident level 2 or higher requiring medical resources. Moreover, for patients who died in the hospital, the death date was used as a censoring date. For patients without falls, the discharge date was used as a censoring date. The classification of fall incident or accident levels [12] is shown in Supplementary Table 1. Based on the 1987 Kellogg International Work Group on Fall Prevention in the Elderly [13], the definition of a fall was an unintentional landing of any part of the body other than the sole on the same or lower surface. It also includes falls from wheelchairs and beds.

For the inpatients at the Shizuoka General Hospital in 2019, the average length of stay was 11.4 days, and that for the DPC-specific hospital group in the same year was 11.3 days [14]. In this study, the average length of stay for inpatients was 12.9 days, and 90.8 % of the patients were discharged within 28 days of admission (Figure 2). Therefore, we examined a model to predict falls within 28 days of admission.

Statistical analysis

Demographic data and the distribution of candidate predictors at hospitalisation were summarised as mean \pm standard deviation or maximum (range) for continuous variables; distribution type and frequency (%) were considered for categorical variables. Additionally, t-tests for continuous variables and chi-square tests for categorical variables were performed to compare any differences between groups. Finally, the fall rate was estimated by the Kaplan-Meier method.

We explored the risk factors that affect the time from hospital admission to fall. Further, we entered candidate predictors and known predictors that were significant ($p < 0.001$) in comparing patient background tables by fall status into a multivariable Cox proportional hazards model. Factors that were significant in the multivariable model were identified as risk factors. The hazard ratio, 95% confidence interval (CI), and p-value were calculated in the Cox model. Spearman's correlation coefficient was used to confirm independence between the covariates with an absolute value > 0.3 . Further, one of the two items was selected based on its clinical importance and the possibility of collecting data reliably at admission.

In this study, we explored risk factors by performing a one-step stratification on essential variables. This operation improves the predictive performance of the prediction model by accounting for the interactions among the covariates and treating their relationships as non-linear. First, for each variable of interest, the number of other variables for which the absolute value of Spearman's correlation coefficient exceeds 0.3 was counted. Then, from a group of candidate stratification factors with high numbers, clinically meaningful items were selected as stratification factors.

The prediction model was constructed using validation set (2/3 of the inpatients were randomly selected). The remaining test set (1/3 of the inpatients) compared the predicted and measured fall values at 28 days after admission. The prediction performance index of the prediction model was calculated as a c-index. In addition, to compare the prediction model constructed by stratifying essential stratification items with the prediction model without stratification, the percentage of falls when the difference between the predictions is greater than 0 (good stratification model), and less than 0 (wrong stratification model) were compared and evaluated by the chi-square test.

The significance level of the two-tailed test was set at 0.05. All analyses were performed using R version 4.1.0 (R Development Core Team, Vienna, Austria) and SPSS statistical software version 27 (IBM Corp).

Results

Inpatient background and incidence of fall with medical resource

Of the 24,932 inpatients without duplicate IDs, 22,988 were included in the analysis, excluding those not eligible for DPC and 1,944 patients with missing bedriddenness ranks at admission. The mean duration of hospitalisation (observation period of this study) was 12.9 ± 14.8 days (Fig. 2a). Falls during the observation period for the entire sample are shown in Supplementary Table 2. Falls of all incident levels were observed in 653 (2.8 %) patients, and falls with medical resource were observed in 400 (1.7 %) patients (Fig. 2b). Details of the number of falls with medical resource by bedridden level are shown in Supplementary Table 3.

Stratified Variables (Bedriddenness Rank) And Patient Background

The degree of bedriddenness rank, a clinically significant variable with a high correlation with 17 other variables, was used as the first-stage stratification variable (Supplementary Table 4). Patient background on admission according to the presence or absence of falls in each bedriddenness rank stratum is shown in Table 1. Supplementary Tables 5 and 6 show the patient background at admission according to the presence or absence of falls for each bedridden rank group in the test and validation sets. The background of the entire sample is shown in Supplementary Table 7.

Table 1
Patient background on admission according to the presence or absence of falls in each bedriddenness rank stratum.

| Variable | Category (unit) | Bedriddenness rank | | | | | | | | | | | |
|-----------------------|----------------------|----------------------|--------------|-----------|----------------------|--------------|-----------|----------------------|--------------|-----------|----------------------|--------------|--------|
| | | Rank J (N = 13,866) | | | Rank A (N = 4,403) | | | Rank B (N = 1,439) | | | Rank C (N = 3,280) | | |
| Without fall | With fall | P-value ^a | Without fall | With fall | P-value ^a | Without fall | With fall | P-value ^a | Without fall | With fall | P-value ^a | | |
| N = 13746 | N = 120 | | N = 4288 | N = 115 | | N = 1377 | N = 62 | | N = 3177 | N = 103 | | | |
| Duration of admission | (day) | 10.1 ± 11.2 | 38.7 ± 40.5 | <0.001 | 13.9 ± 14.5 | 32.2 ± 29.2 | <0.001 | 17.1 ± 15.3 | 31.7 ± 21.5 | <0.001 | 19.2 ± 20.1 | 34.2 ± 24.0 | <0.001 |
| Time to fall | (day) | 10.0 ± 10.9 | 18.3 ± 24.4 | <0.001 | 13.6 ± 14.1 | 15.5 ± 21.0 | 0.899 | 16.7 ± 15.1 | 13.8 ± 12.5 | 0.045 | 18.8 ± 19.8 | 16.2 ± 16.7 | 0.082 |
| Age | (years) | 63.4 ± 15.8 | 72.5 ± 11.5 | <0.001 | 70.0 ± 14.9 | 74.7 ± 10.7 | 0.003 | 73.7 ± 14.1 | 77.5 ± 9.5 | 0.095 | 74.1 ± 15.5 | 74.7 ± 13.4 | 0.771 |
| Sex | Women | 6106 (99.4) | 35 (0.6) | 0.001 | 1908 (98.1) | 37 (1.9) | 0.009 | 631 (96.3) | 24 (3.7) | 0.271 | 1511 (97.3) | 42 (2.7) | 0.171 |
| | Men | 7640 (98.9) | 85 (1.1) | | 2380 (96.8) | 78 (3.2) | | 746 (95.2) | 38 (4.8) | | 1666 (96.5) | 61 (3.5) | |
| Height | (cm) | 161.0 ± 8.9 | 161.0 ± 8.7 | 0.952 | 158.7 ± 9.8 | 159.3 ± 8.5 | 0.492 | 157.1 ± 10.2 | 155.9 ± 9.5 | 0.357 | 157.3 ± 10.4 | 159.7 ± 10.0 | 0.541 |
| Weight | (kg) | 60.3 ± 12.9 | 56.9 ± 11.5 | 0.004 | 56.8 ± 12.9 | 55.3 ± 12.5 | 0.206 | 55.7 ± 12.7 | 51.1 ± 12.5 | 0.110 | 53.8 ± 13.8 | 51.8 ± 12.7 | 0.141 |
| BMI | (kg/m ²) | 23.1 ± 4.1 | 21.9 ± 3.9 | 0.001 | 22.5 ± 4.3 | 21.6 ± 3.9 | 0.040 | 21.7 ± 4.4 | 20.9 ± 4.1 | 0.147 | 21.6 ± 4.3 | 20.9 ± 3.7 | 0.111 |
| Emergency admission | No | 11247 (99.3) | 77 (0.7) | <0.001 | 2078 (97.7) | 49 (2.3) | 0.316 | 231 (94.7) | 13 (5.3) | 0.623 | 185 (98.9) | 2 (1.1) | 0.201 |
| | Yes | 2412 (98.2) | 43 (1.8) | | 2187 (97.1) | 66 (2.9) | | 1141 (95.9) | 49 (4.1) | | 2982 (96.7) | 101 (3.3) | |
| | Missing category | 87 (100) | 0 (0) | | 23 (100) | 0 (0) | | 5 (100) | 0 (0) | | 10 (100) | 0 (0) | |
| Ambulance transport | No | 13362 (99.2) | 107 (0.8) | <0.001 | 3705 (97.5) | 96 (2.5) | 0.367 | 972 (95.7) | 44 (4.3) | 0.949 | 1037 (97.8) | 23 (2.2) | 0.021 |
| | Yes | 384 (96.7) | 13 (3.3) | | 583 (96.8) | 19 (3.2) | | 405 (95.7) | 18 (4.3) | | 2140 (96.4) | 80 (3.6) | |
| Dementia | Absence | 13371 (99.1) | 117 (0.9) | 0.879 | 4154 (97.4) | 111 (2.6) | 0.830 | 1344 (95.7) | 61 (4.3) | 0.691 | 3099 (96.8) | 101 (3.2) | 0.741 |
| | Presence | 375 (99.2) | 3 (0.8) | | 134 (97.1) | 4 (2.9) | | 33 (97.1) | 1 (2.9) | | 78 (97.5) | 2 (2.5) | |
| Parkinson's disease | Absence | 13702 (99.1) | 120 (0.9) | 0.535 | 4230 (97.4) | 111 (2.6) | 0.056 | 1345 (95.7) | 61 (4.3) | 0.714 | 3108 (96.9) | 99 (3.1) | 0.241 |
| | Presence | 44 (100) | 0 (0) | | 58 (93.5) | 4 (6.5) | | 32 (97.0) | 1 (3.0) | | 69 (94.5) | 4 (5.1) | |
| Stroke | Absence | 13008 (99.2) | 104 (0.8) | <0.001 | 3735 (97.5) | 96 (2.5) | 0.254 | 1115 (95.8) | 49 (4.2) | 0.704 | 2515 (96.9) | 81 (3.1) | 0.891 |
| | Presence | 738 (97.9) | 16 (2.1) | | 553 (96.7) | 19 (3.3) | | 262 (95.3) | 13 (4.7) | | 662 (96.8) | 22 (3.2) | |
| Visual impairment | Absence | 13008 (99.2) | 104 (0.8) | <0.001 | 3688 (97.4) | 98 (2.6) | 0.810 | 1145 (95.8) | 50 (4.2) | 0.607 | 2799 (96.6) | 98 (3.4) | 0.021 |
| | Presence | 659 (98.2) | 12 (1.8) | | 600 (97.2) | 17 (2.8) | | 232 (95.1) | 12 (4.9) | | 378 (98.7) | 5 (1.3) | |
| Use of care insurance | No | 2799 (99.0) | 28 (1.0) | 0.001 | 804 (98.0) | 16 (2.0) | 0.149 | 179 (95.7) | 8 (4.3) | 0.962 | 557 (96.9) | 18 (3.1) | 0.401 |

Note: Categorical variables are presented as the number of patients and percentages, and continuous variables are presented as mean and standard error.

Abbreviation: BMI, body mass index.

^a Bedriddenness rank: J, independence/autonomy; A, housebound; B, chair-bound; C, bed-bound.

^b Intergroup comparison was made using the t-test and chi-square test for continuous and categorical variables, respectively.

| Variable | Category (unit) | Bedriddenness rank | | | | | | | | | | | |
|------------------------------|---------------------------------------|---------------------|-----------------|-----------|--------------------|----------------|----------|--------------------|----------------|----------|--------------------|----------------|-------------|
| | | Rank J (N = 13,866) | | | Rank A (N = 4,403) | | | Rank B (N = 1,439) | | | Rank C (N = 3,280) | | |
| | Yes | 651 (97.9) | 14 (2.1) | | 907 (96.6) | 32 (3.4) | | 576 (95.5) | 27 (4.5) | | 1304 (97.3) | 36 (2.7) | |
| | Missing category | 10296 (99.2) | 78 (0.8) | | 2577 (97.5) | 67 (2.5) | | 622 (95.8) | 27 (4.2) | | 1316 (96.4) | 49 (3.6) | |
| | Presence of cognitive function scores | No | 12971 (99.1) | 117 (0.9) | 0.049 | 3896 (97.5) | 98 (2.5) | 0.004 | 1097 (95.9) | 47 (4.1) | 0.481 | 2303 (97.1) | 69 (2.9) |
| | Yes | 200 (98.5) | 3 (1.5) | | 311 (94.8) | 17 (5.2) | | 266 (94.7) | 15 (5.3) | | 820 (96.0) | 34 (4.0) | |
| | Missing category | 575 (100) | 0 (0) | | 81 (100) | 0 (0) | | 14 (100) | 0 (0) | | 54 (100) | 0 (0) | |
| Inpatient ward | Internal medicine | 7407 (99.2) | 63 (0.8) | 0.009 | 2492 (97.6) | 60 (2.4) | 0.435 | 888 (95.7) | 40 (4.3) | 0.878 | 1586 (97.0) | 49 (3.0) | 0.581 |
| | Department of Surgery | 6229 (99.2) | 53 (0.8) | | 1687 (97.0) | 52 (3.0) | | 399 (95.9) | 17 (4.1) | | 1038 (97.0) | 32 (3.0) | |
| | Emergency Department | 110 (96.5) | 4 (3.5) | | 109 (97.3) | 3 (2.7) | | 90 (94.7) | 5 (5.3) | | 553 (96.2) | 22 (3.8) | |
| Disturbance of consciousness | Absence | 13583 (99.2) | 115 (0.8) | 0.011 | 3974 (97.5) | 101 (2.5) | 0.143 | 1113 (95.5) | 52 (4.5) | 0.823 | 1836 (97.6) | 45 (2.4) | 0.011 |
| | Presence | 162 (97.0) | 5 (3.0) | | 313 (95.7) | 14 (4.3) | | 263 (96.3) | 10 (3.7) | | 1340 (95.9) | 58 (4.1) | |
| | Missing category | 1 (100) | 0 (0.0) | | 1 (100) | 0 (0) | | 1 (100) | 0 (0) | | 1 (100) | 0 (0) | |
| Eating | Independent | 13430 (99.3) | 101 (0.7) | <0.001 | 3386 (97.8) | 76 (2.2) | 0.004 | 500 (97.3) | 14 (2.7) | 0.086 | 547 (98.9) | 6 (1.1) | 0.001 |
| | Requiring assistance | 287 (94.1) | 18 (5.9) | | 851 (95.8) | 37 (4.2) | | 844 (94.8) | 46 (5.2) | | 2513 (96.4) | 94 (3.6) | |
| | Missing category | 29 (96.7) | 1 (3.3) | | 51 (96.2) | 2 (3.8) | | 33 (94.3) | 2 (5.7) | | 117 (97.5) | 3 (2.5) | |
| Transferring | Independent | 13111 (93.3) | 99 (0.7) | <0.001 | 2759 (98.2) | 51 (1.8) | <0.001 | 276 (97.5) | 7 (2.5) | 0.109 | 404 (99.0) | 4 (1.0) | 0.021 |
| | Requiring assistance | 627 (96.8) | 21 (3.2) | | 1517 (96.0) | 64 (4.0) | | 1095 (95.3) | 54 (4.7) | | 2750 (96.6) | 98 (3.4) | |
| | Missing category | 8 (100) | 0 (0) | | 12 (100) | 0 (0) | | 6 (85.7) | 1 (14.3) | | 23 (95.8) | 1 (4.2) | |
| Dressing | Independent | 13444 (99.2) | 104 (0.8) | <0.001 | 3425 (97.6) | 85 (2.4) | 0.137 | 514 (97.5) | 13 (2.5) | 0.004 | 525 (98.7) | 7 (1.3) | 0.021 |
| | Requiring assistance | 278 (94.9) | 15 (5.1) | | 830 (96.5) | 30 (3.5) | | 845 (94.8) | 46 (5.2) | | 2587 (96.5) | 95 (3.5) | |
| | Missing category | 24 (96.0) | 1 (4.0) | | 33 (100) | 0 (0) | | 18 (85.7) | 3 (14.3) | | 65 (98.5) | 1 (1.5) | |
| Moving and using the toilet | Independent | 13338 (99.2) | 105 (0.8) | <0.001 | 3109 (98.0) | 65 (2.0) | 0.001 | 362 (98.1) | 7 (1.9) | 0.030 | 440 (98.9) | 5 (1.1) | 0.021 |
| | Requiring assistance | 387 (96.3) | 15 (3.7) | | 1149 (95.9) | 49 (4.1) | | 998 (94.9) | 54 (5.1) | | 2660 (96.5) | 96 (3.5) | |
| | Missing category | 21 (100) | 0 (0) | | 30 (96.8) | 1 (3.2) | | 17 (94.4) | 1 (5.6) | | 77 (97.5) | 2 (2.5) | |
| Bathing | Independent | 13229 (99.2) | 101 (0.8) | <0.001 | 2875 (98.0) | 60 (2.0) | 0.002 | 309 (98.4) | 5 (1.6) | 0.018 | 419 (99.1) | 4 (0.9) | 0.011 |
| | Requiring assistance | 428 (96.2) | 17 (3.8) | | 1146 (96.1) | 47 (3.9) | | 912 (94.7) | 51 (5.3) | | 2526 (96.5) | 92 (3.5) | |

Note: Categorical variables are presented as the number of patients and percentages, and continuous variables are presented as mean and standard error.

Abbreviation: BMI, body mass index.

^a Bedriddenness rank: J, independence/autonomy; A, housebound; B, chair-bound; C, bed-bound.

^b Intergroup comparison was made using the t-test and chi-square test for continuous and categorical variables, respectively.

| Variable | Category (unit) | Bedriddenness rank | | | | | | | | | | | |
|------------------------------|----------------------|---------------------|-----------|--------|--------------------|----------|--------|--------------------|----------|-------|--------------------|----------|-------|
| | | Rank J (N = 13,866) | | | Rank A (N = 4,403) | | | Rank B (N = 1,439) | | | Rank C (N = 3,280) | | |
| | Missing category | 89 (97.8) | 2 (2.2) | | 267 (97.1) | 8 (2.9) | | 156 (96.3) | 6 (3.7) | | 232 (97.1) | 7 (2.9) | |
| Walking on level ground | Independent | 13234 (99.2) | 101 (0.8) | <0.001 | 2947 (98.1) | 56 (1.9) | <0.001 | 305 (97.8) | 7 (2.2) | 0.093 | 424 (99.1) | 4 (0.9) | 0.014 |
| | Requiring assistance | 474 (96.3) | 18 (3.7) | | 1239 (95.5) | 58 (4.5) | | 983 (95.0) | 52 (5.0) | | 2560 (96.5) | 94 (3.5) | |
| | Missing category | 38 (97.4) | 1 (2.6) | | 102 (99.0) | 1 (1.0) | | 89 (96.7) | 3 (3.3) | | 193 (97.5) | 5 (2.5) | |
| Stair climbing | Independent | 13069 (99.3) | 97 (0.7) | <0.001 | 2672 (98.2) | 50 (1.8) | <0.001 | 284 (98.3) | 5 (1.7) | 0.040 | 404 (99.0) | 4 (1.0) | 0.010 |
| | Requiring assistance | 484 (96.6) | 17 (3.4) | | 1123 (95.8) | 49 (4.2) | | 815 (94.8) | 45 (5.2) | | 2490 (96.4) | 93 (3.6) | |
| | Missing category | 193 (97.0) | 6 (3.0) | | 493 (96.9) | 16 (3.1) | | 278 (95.9) | 12 (4.1) | | 283 (97.9) | 6 (2.1) | |
| Changing clothes | Independent | 13303 (99.2) | 102 (0.8) | <0.001 | 3086 (97.8) | 68 (2.2) | 0.004 | 354 (97.8) | 8 (2.2) | 0.068 | 437 (98.9) | 5 (1.1) | 0.030 |
| | Requiring assistance | 425 (96.2) | 17 (3.8) | | 1167 (96.1) | 47 (3.9) | | 994 (94.9) | 53 (5.1) | | 2702 (96.5) | 97 (3.5) | |
| | Missing category | 18 (94.7) | 1 (5.3) | | 35 (100) | 0 (0) | | 29 (96.7) | 1 (3.3) | | 38 (97.4) | 1 (2.6) | |
| Defecation management | Independent | 13503 (99.2) | 105 (0.8) | <0.001 | 3649 (97.6) | 90 (2.4) | 0.109 | 640 (96.4) | 24 (3.6) | 0.246 | 605 (97.3) | 17 (2.7) | 0.370 |
| | Requiring assistance | 212 (93.4) | 15 (6.6) | | 568 (96.1) | 23 (3.9) | | 683 (94.9) | 37 (5.1) | | 2436 (96.7) | 84 (3.3) | |
| | Missing category | 31 (100) | 0 (0) | | 71 (97.3) | 2 (2.7) | | 54 (98.2) | 1 (1.8) | | 136 (98.6) | 2 (1.4) | |
| Urination management | Independent | 13493 (99.2) | 105 (0.8) | <0.001 | 3638 (97.6) | 89 (2.4) | 0.076 | 639 (96.7) | 22 (3.3) | 0.205 | 592 (97.4) | 16 (2.6) | 0.170 |
| | Requiring assistance | 226 (93.8) | 15 (6.2) | | 580 (96.0) | 24 (4.0) | | 681 (95.0) | 36 (5.0) | | 2455 (96.6) | 86 (3.4) | |
| | Missing category | 27 (100) | 0 (0) | | 70 (97.2) | 2 (2.8) | | 57 (93.4) | 4 (6.6) | | 130 (99.2) | 1 (0.8) | |
| Good sleep condition | Yes | 8885 (99.2) | 70 (0.8) | 0.008 | 2134 (97.0) | 66 (3.0) | 0.206 | 504 (95.5) | 24 (4.5) | 0.938 | 774 (97.5) | 20 (2.5) | 0.380 |
| | No | 1951 (98.5) | 29 (1.5) | | 759 (97.4) | 20 (2.6) | | 245 (95.7) | 11 (4.3) | | 231 (95.9) | 10 (4.1) | |
| | Missing category | 2910 (99.3) | 21 (0.7) | | 1395 (98.0) | 29 (2.0) | | 628 (95.9) | 27 (4.1) | | 2172 (96.7) | 73 (3.3) | |
| Use of sleeping pills | Absence | 8138 (99.2) | 66 (0.8) | 0.276 | 1931 (97.1) | 57 (2.9) | 0.149 | 465 (95.1) | 24 (4.9) | 0.639 | 527 (97.1) | 16 (2.9) | 0.950 |
| | Presence | 1451 (99.8) | 18 (1.2) | | 539 (96.6) | 19 (3.4) | | 162 (95.3) | 8 (4.7) | | 209 (96.8) | 7 (3.2) | |
| | Missing category | 4157 (99.1) | 36 (0.9) | | 1818 (97.9) | 39 (2.1) | | 750 (96.2) | 30 (3.8) | | 2441 (96.8) | 80 (3.2) | |
| Medication management status | Myself | 6801 (99.3) | 50 (0.7) | <0.001 | 1422 (97.7) | 33 (2.3) | 0.025 | 235 (95.5) | 11 (4.5) | 0.661 | 190 (95.5) | 9 (4.5) | 0.170 |
| | Others | 263 (97.0) | 8 (3.0) | | 312 (95.1) | 16 (4.9) | | 191 (94.6) | 11 (5.4) | | 255 (98.5) | 4 (1.5) | |
| | Missing category | 6682 (99.1) | 62 (0.9) | | 2554 (97.5) | 66 (2.5) | | 951 (96.0) | 40 (4.0) | | 2732 (96.8) | 90 (3.2) | |

Note: Categorical variables are presented as the number of patients and percentages, and continuous variables are presented as mean and standard error.

Abbreviation: BMI, body mass index.

^a Bedriddenness rank: J, independence/autonomy; A, housebound; B, chair-bound; C, bed-bound.

^b Intergroup comparison was made using the t-test and chi-square test for continuous and categorical variables, respectively.

| Variable | Category (unit) | Bedriddenness rank | | | | | | | | | | | |
|-------------------------------------|------------------|---------------------|----------|--------|--------------------|----------|-------|--------------------|--------------|-------|--------------------|-------------|-------|
| | | Rank J (N = 13,866) | | | Rank A (N = 4,403) | | | Rank B (N = 1,439) | | | Rank C (N = 3,280) | | |
| History of falls within 1 year | Absence | 11837 (99.3) | 88 (0.7) | <0.001 | 3252 (97.7) | 75 (2.3) | 0.003 | 905 (96.4) | 34 (3.6) | 0.052 | 1798 (97.2) | 52 (2.8) | 0.364 |
| | Presence | 766 (97.5) | 20 (2.5) | | 548 (95.3) | 27 (4.7) | | 270 (93.1) | 20 (6.9) | | 827 (96.2) | 33 (3.8) | |
| | Missing category | 1143 (99.0) | 12 (1.0) | | 488 (97.4) | 13 (2.6) | | 202 (96.2) | 8 (3.8) | | 552 (96.8) | 18 (3.2) | |
| Inability to stand without holding | Absence | 10304 (99.4) | 61 (0.6) | <0.001 | 1318 (98.5) | 20 (1.5) | 0.003 | 92 (98.9) | 1 (1.1) | 0.234 | 253 (98.8) | 3 (1.2) | 0.124 |
| | Presence | 2240 (97.8) | 50 (2.2) | | 2688 (96.8) | 90 (3.2) | | 1221 (95.4) | 559 (4.6) | | 2720 (96.8) | 91 (3.2) | |
| | Missing category | 1202 (99.3) | 9 (0.7) | | 282 (98.3) | 5 (1.7) | | 64 (97.0) | 2 (3.0) | | 204 (95.8) | 9 (4.2) | |
| Impaired judgment and comprehension | Absence | 12014 (99.2) | 95 (0.8) | <0.001 | 3273 (97.6) | 80 (2.4) | 0.032 | 864 (96.0) | 36 (4.0) | 0.557 | 1399 (97.0) | 43 (3.0) | 0.690 |
| | Presence | 373 (96.9) | 12 (3.1) | | 511 (95.7) | 23 (4.3) | | 318 (94.6) | 18 (5.4) | | 1320 (96.6) | 47 (3.4) | |
| | Missing category | 1359 (99.1) | 13 (0.9) | | 504 (97.7) | 12 (2.3) | | 195 (96.1) | 8 (3.9) | | 458 (97.2) | 13 (2.8) | |
| Toileting assistance | Absence | 11578 (99.2) | 91 (0.8) | 0.003 | 2697 (98.0) | 56 (2.0) | 0.001 | 388 (97.7) | 9 (2.3) | 0.025 | 709 (96.6) | 25 (3.4) | 0.734 |
| | Presence | 442 (97.8) | 10 (2.2) | | 1070 (95.8) | 47 (4.2) | | 811 (94.5) | 47 (5.5) | | 1941 (97.1) | 59 (2.9) | |
| | Missing category | 1726 (98.9) | 19 (1.1) | | 521 (97.7) | 12 (2.3) | | 178 (96.7) | 6 (3.3) | | 527 (96.5) | 19 (3.5) | |
| Use of portable toilet | Absence | 11314 (99.2) | 93 (0.8) | 0.031 | 3122 (97.7) | 74 (2.3) | 0.039 | 821 (96.2) | 32 (3.8) | 0.117 | 2170 (97.0) | 68 (3.0) | 0.564 |
| | Presence | 194 (97.5) | 5 (2.5) | | 444 (95.7) | 20 (4.3) | | 273 (93.5) | 19 (6.5) | | 121 (95.3) | 6 (4.7) | |
| | Missing category | 2238 (99.0) | 22 (1.0) | | 722 (97.2) | 21 (2.8) | | 283 (96.3) | 11 (3.7) | | 886 (96.8) | 29 (3.2) | |

Note: Categorical variables are presented as the number of patients and percentages, and continuous variables are presented as mean and standard error.

Abbreviation: BMI, body mass index.

^a Bedriddenness rank: J, independence/autonomy; A, housebound; B, chair-bound; C, bed-bound.

^b Intergroup comparison was made using the t-test and chi-square test for continuous and categorical variables, respectively.

Predictors Of Falls By The Level Of Bedriddenness Rank

Variables with an absolute value of Spearman's correlation coefficient higher than 0.3 (Supplementary Table 4) were narrowed down, and variables with $p < 0.001$ or lower were entered into the Multivariable model. Stratified multivariable analysis in the validation set (N = 15,426) showed that the fall risk factors (high risk) were age (high), sex (men), and ambulance transport (yes) for rank J (independent); age (high), and sex (men) for rank A (semi-sedentary). There was no predictor for rank B (bedridden); and ophthalmologic disease (no) for rank C (Table 2).

Table 2
Multivariable Cox proportional hazards model by bedriddenness rank (validation set, N = 15,426)

| Subgroup by | Variable (reference group) | Category or unit | HR | 95%CI | P-value ^b |
|---|--|----------------------|--------------|--------------|----------------------|
| bedriddenness rank^a | | | | | |
| Rank J | Age | years | 1.04 | 1.02 to 1.05 | <0.001 |
| | Sex (women) | Men | 1.52 | 1.02 to 2.27 | 0.041 |
| | Ambulance transport (no) | Yes | 2.05 | 1.10 to 3.79 | 0.023 |
| | BMI | 1Kg/m ² | 0.96 | 0.91 to 1.00 | 0.071 |
| | Medication management status (myself) | Others | 2.19 | 1.02 to 4.71 | 0.134 |
| | | Missing category | 1.15 | 0.78 to 1.70 | |
| | Inability to stand without holding (absence) | Presence | 1.67 | 1.10 to 2.53 | 0.054 |
| Missing category | | 1.13 | 0.56 to 2.30 | | |
| Rank A | Age | years | 1.02 | 1.00 to 1.03 | 0.044 |
| | Sex (women) | Men | 1.68 | 1.13 to 2.48 | 0.010 |
| | BMI | 1Kg/m ² | 0.98 | 0.93 to 1.03 | 0.359 |
| | Transferring (independent) | Requiring assistance | 1.4 | 0.95 to 2.07 | 0.086 |
| | Medication management status (myself) | Others | 1.72 | 0.93 to 3.17 | 0.160 |
| | | Missing category | 1.03 | 0.67 to 1.57 | |
| Rank B | Dressing (independent) | Requiring assistance | 1.57 | 0.84 to 2.93 | 0.156 |
| | History of falls within 1 year (absence) | Presence | 1.97 | 1.12 to 3.47 | 0.063 |
| | | Missing category | 1.24 | 0.57 to 2.70 | |
| Rank C | Ambulance transport (no) | Yes | 1.34 | 0.84 to 2.15 | 0.220 |
| | Visual impairment (absence) | Presence | 0.35 | 0.14 to 0.86 | 0.022 |
| | Transferring (independent) | Requiring assistance | 1.81 | 0.65 to 5.05 | 0.254 |
| | Disturbance of consciousness (absence) | Presence | 1.32 | 0.88 to 1.98 | 0.173 |
| Abbreviation: BMI, body mass index, HR, hazards ratio; CI, confidence interval. | | | | | |
| ^a Bedriddenness rank: J, independence/autonomy; A, housebound; B, chair-bound; C, bed-bound. | | | | | |
| ^b P-value for Wald test. | | | | | |

The results of unstratified multivariable analysis in the validation set are shown in Supplementary Table 8. Fall risk factors (high risk) were age (high), sex (men), BMI at admission (low), department (internal medicine versus emergency department), history of falls within one year (yes), and degree of bedriddenness rank (J versus A and B).

Testing Of Fall Prediction Models

In test set (N = 7,562), the c-index as the performance of the stratified prediction model's performance for falls within 28 days was 0.705 (95 % CI, 0.664–0.746) (Table 3). Hosmer-Lemeshow goodness-of-fit statistics were significant, as a result of the high number of cases ($\chi^2 = 192.06$; 8 degrees of freedom; $p < 0.001$; Fig. 3). The c-index for model without stratification was 0.703 (95 % CI, 0.661–0.746), indicating that the prediction accuracy of the model stratified by bedriddenness rank was high ($p < 0.001$, Fig. 4).

Table 3
Predictive performance of models for fall within 28 days by bedriddenness rank (test set, N = 7,562)

| Model | Subgroup | C-index (95%CI) of model for falls within 28 days |
|---|--------------------|---|
| Integrated model by bedriddenness rank ^a | Total (N = 7,562) | 0.705 (0.664–0.746) |
| | Rank J (N = 4,592) | 0.707 (0.631–0.783) |
| | Rank A (N = 1,437) | 0.633 (0.537–0.730) |
| | Rank B (N = 470) | 0.564 (0.467–0.661) |
| | Rank C (N = 1,063) | 0.546 (0.453–0.639) |
| Unstratified model ^b | Total (N = 7,737) | 0.703 (0.661–0.746) |
| Abbreviation: CI, confidence interval. | | |
| ^a Integrated model by bedriddenness rank is a model integrated after modelling stratified by bedriddenness rank. | | |
| ^b Unstratified model is a model for all analysis individuals. | | |

Discussion

The current study was a retrospective cohort study conducted at a single institution specialising in acute inpatient care and identified risk factors for falls by stratification of bedriddenness rank. The risk factors (high risk) for falls according to the degree of bedriddenness rank were age (high), sex (men), and ambulance transport (yes) for rank J (independent); age (high), and sex (men) for rank A (semi-bedridden); no predictors for the rank B (chair-bound); and ophthalmologic disease (no) for rank C (bed-bound). Additionally, we constructed a prediction model for falls within 28 days after hospitalisation according to the degree of bedriddenness rank. The predictive performance of this model was higher than that of the models that were not divided by bedriddenness rank.

In our analysis of inpatients aged 20 years and older, age was a determinant of falls in patients with bedriddenness ranks J and A. This result is similar to previous reports [15, 16] in which older age was a risk factor for falls. Conversely, age was not a predictor of falls in inpatients with bedridden ranks B and C. This indicates that older age in bedridden inpatients did not increase the risk of falls.

Furthermore, we confirmed that being a men is a risk factor for in-hospital falls in inpatients with bedridden ranks J and A. Previous similar reports [4, 17] were based on patients admitted to medical institutions. In contrast, reports that being a women was a risk factor for falls [18] were based on relatively healthy community residents. However, patients admitted to a medical institution for some acute diseases are considered to have activity limitations associated with the treatment of the disease. Additionally, changes in pain, fatigue, anxiety, and sleep disturbances [19] may constitute a population that includes some additional factors as decreased physical activity. Therefore, sex as a risk factor for falls may differ when comparing community-dwelling people who lead relatively healthy lives with a hospitalised population in a medical institution.

Previous reports on risk factors for in-hospital falls in hospitalised patients [4–7] have shown that the risk factors for falls differ between these models. Some of these suggest that a decline in ADL is associated with falls [4–6]. For the bedriddenness rank that we chose as an essential stratum, 12 of the 17 strongly correlated variables were related to ADL. In the future, it may be helpful to model the prediction of falls by efficiently using many ADL-related variables.

Emergency hospitalisation was identified as a risk factor for in-hospital falls in inpatients with bedriddenness rank J (inpatients with independent mobility). Rapid deterioration of the patient's condition after hospitalisation was thought to be the reason. In the future, it is necessary to investigate changes in the condition of these patients and search for additional information that is important for fall prediction.

It has been reported that the incidence of falls is higher in the elderly with visual impairment than those without [20–22], and falls in the elderly often lead to severe complications [23]. The majority of eye diseases that cause visual impairment are age-related diseases such as cataracts and glaucoma. Therefore, in this survey, the possibility that visual impairment may affect falls was also considered in the analysis. However, visual impairment was not identified as a risk factor in either the total or the subgroups. Interestingly, the absence of ophthalmological diseases such as cataracts and glaucoma was identified as a risk factor for in-hospital falls in the bedridden rank C patients with the most reduced motor function. The absence of visual impairment may induce bedridden hospitalised patients to become more active in their daily lives. However, it is speculated that insufficient support, such as environmental adjustments to enable patients to be active safely and the assumption that patients were not at high risk for falls, may have led to their falls. Therefore, it was suggested that new interventions to prevent falls in the hospital would be necessary for patients without visual impairment and with bedriddenness rank C (bed-bound).

We suggest direct fall prevention interventions related to high-risk factors for in-hospital falls based on the above discussion. First, for patients with bedriddenness rank J and A who are transported to the emergency room with relatively high mobility, it may be necessary to observe their symptoms to prevent falls. In particular, attention should be paid to men, those with reduced mobility, and falls associated with the severity of the disease. Moreover, patients with rank C and no visual impairment need to recognise that they are a high-risk group for falls and develop a safe environment around their beds, such as railing in the hospital room.

We were able to improve the prediction accuracy of the prediction model by identifying risk factors for falls. This was done by using a sufficiently large number of factors with a one-step stratification of the degree of bedriddenness rank as an important prognostic factor. The model developed in this study can calculate the probability of falls for hospitalised patients using medical record data at the time of admission. We plan to implement it as a tool in our

hospital's electronic medical record terminal. If the risk of falls is assessed after patients are admitted to the hospital and preventive interventions are provided to the high-risk group, the number of falls can be reduced.

DPC is an index that classifies patients according to the combination of diagnosis, treatment, and procedure and adapts the Diagnosis Related Group (DRG) developed in the U.S. [24]. In a group of hospitals specialising in DPC, it is necessary to create an evaluation tool for predicting hospital falls with evidence tailored to the characteristics of each facility to meet the challenges of shortening the average length of stay and maintaining bed occupancy rates. Therefore, it would be meaningful to construct a model for predicting in-hospital falls of patients that consider the characteristics of acute care hospitals' facilities.

Limitation

There are several limitations of this study. First, it is challenging to generalise the results to other hospitals because this study is a retrospective study. Further, the prediction model of in-hospital falls was constructed considering the characteristics of facilities among acute care hospitals. However, there is a possibility that the predictors and the prediction model obtained in this study can be applied to 165 other DPC-specific hospitals in Japan with similar facility characteristics and patient backgrounds. Second, this study did not examine psychiatric symptoms, including delirium [25–27]. However, since previous studies [5, 6] have shown that psychiatric symptoms can be a risk factor for falls, it is necessary to reconstruct the prediction model by adding new predictors of falls, including psychiatric symptoms such as delirium, if they are newly identified. Third, we did not examine the relationship between medications and falls in this study. Since previous studies have shown that the use of sleeping pills [4, 7, 28] and the number of medications [29] can be risk factors for falls, future studies should also take into account other factors that affect falls, such as the type and number of medications taken. Fourth, this study did not use machine learning for prediction because we wanted to preserve the interpretability of the risk factors. However, if further attempts to improve the prediction performance of falls are needed in the future, it would be better to use machine learning to build a prediction model. Despite these limitations, this study has practical implications for developing predictors of falls and prediction tools.

Conclusion

We identified predictors of falls in a population by important ADL (bedriddenness rank) and developed a prediction model. This predictive model enables preventive interventions for individual hospitalised patients and high-risk populations. This fall prediction model can be implemented in many acute care hospitals in Japan, lead to further medical safety, and provide ADL-related factors for fall prevention in hospitals worldwide.

Abbreviation List

ADL, Activities of Daily Living;

BMI, Body Mass Index;

CI, Confidence Interval;

DPC, Diagnosis Procedure Combination;

DRG, Diabetes Procedure Combination;

IBM, International Business Machines Corporation;

ID, identification;

MHLW, Ministry of Health, Labour and Welfare;

SPSS, Statistical Package for Social Science.

Declarations

Ethics approval and consent to participate

This study conforms to the Ethical Principles for Medical Research Involving Human Subjects issued by the Ministry of Health, Labour and Welfare and the Ministry of Education, Culture, Sports, Science, and Technology in Japan. Following these guidelines, the Shizuoka General Hospital Research Ethical Committee determined that individual patient informed consent was not required because this study analysed existing information and patients were given the right to refuse participation by disclosure. After obtaining the approval of this committee (SGHIRB #2020075) and publishing the disclosure document on Shizuoka General Hospital's website, the information of each individual was anonymised, and the analysis was conducted.

Consent for publication

Not applicable.

Availability of data and materials

The datasets and analysed during the current study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Study concept and design: CS, EN, YS; acquisition of data: CS, KH, MY, SU, KO; data analysis: CS, EN, YS; interpretation of data: CS, EN, YS, NK, MT; first draft of the manuscript: CS; All authors reviewed and approved the final manuscript for submission.

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Figures

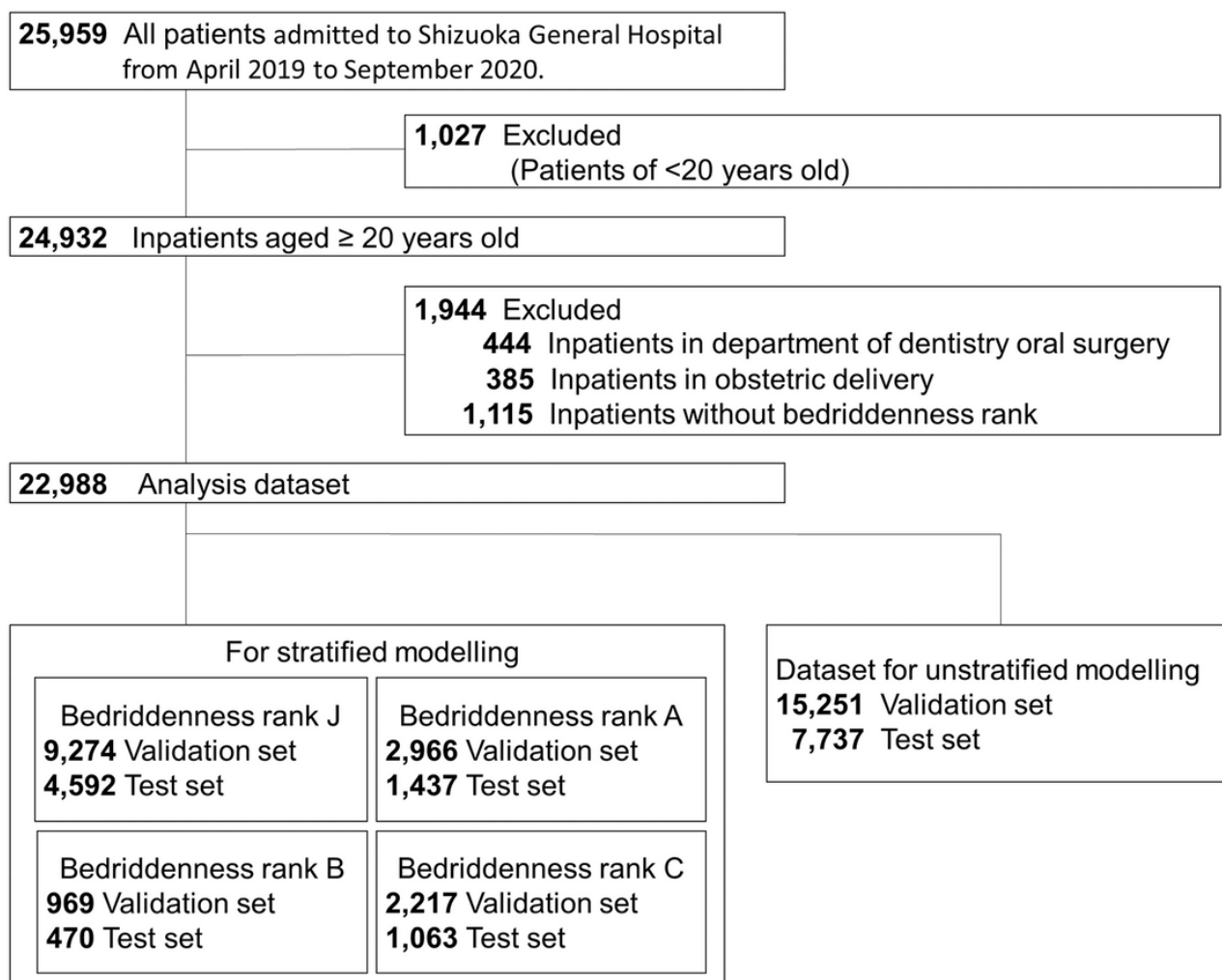


Figure 1

Data flow diagram

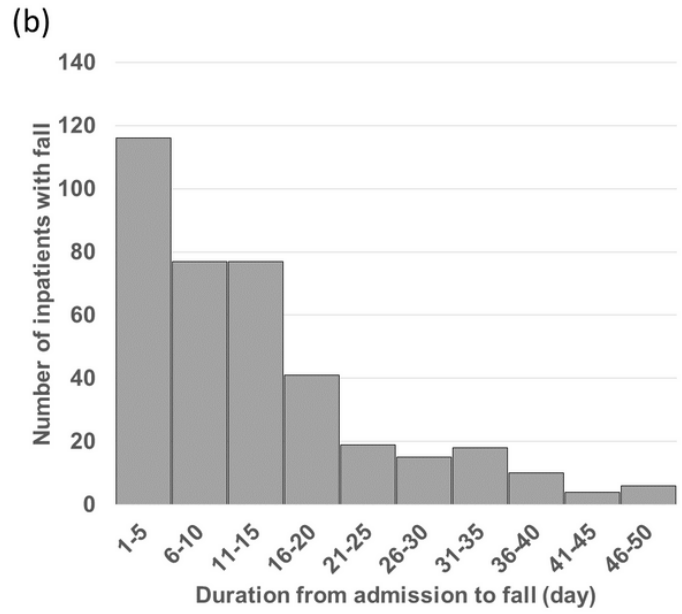
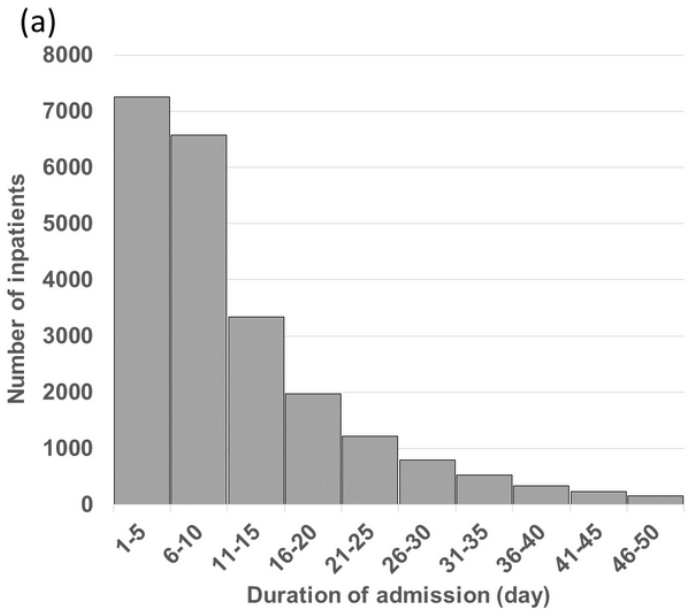


Figure 2
 Distribution of the duration of admission and time to fall. We showed (a) the duration of admission for 22,988 cases and (b) the time to fall with medical resources for 400 cases.

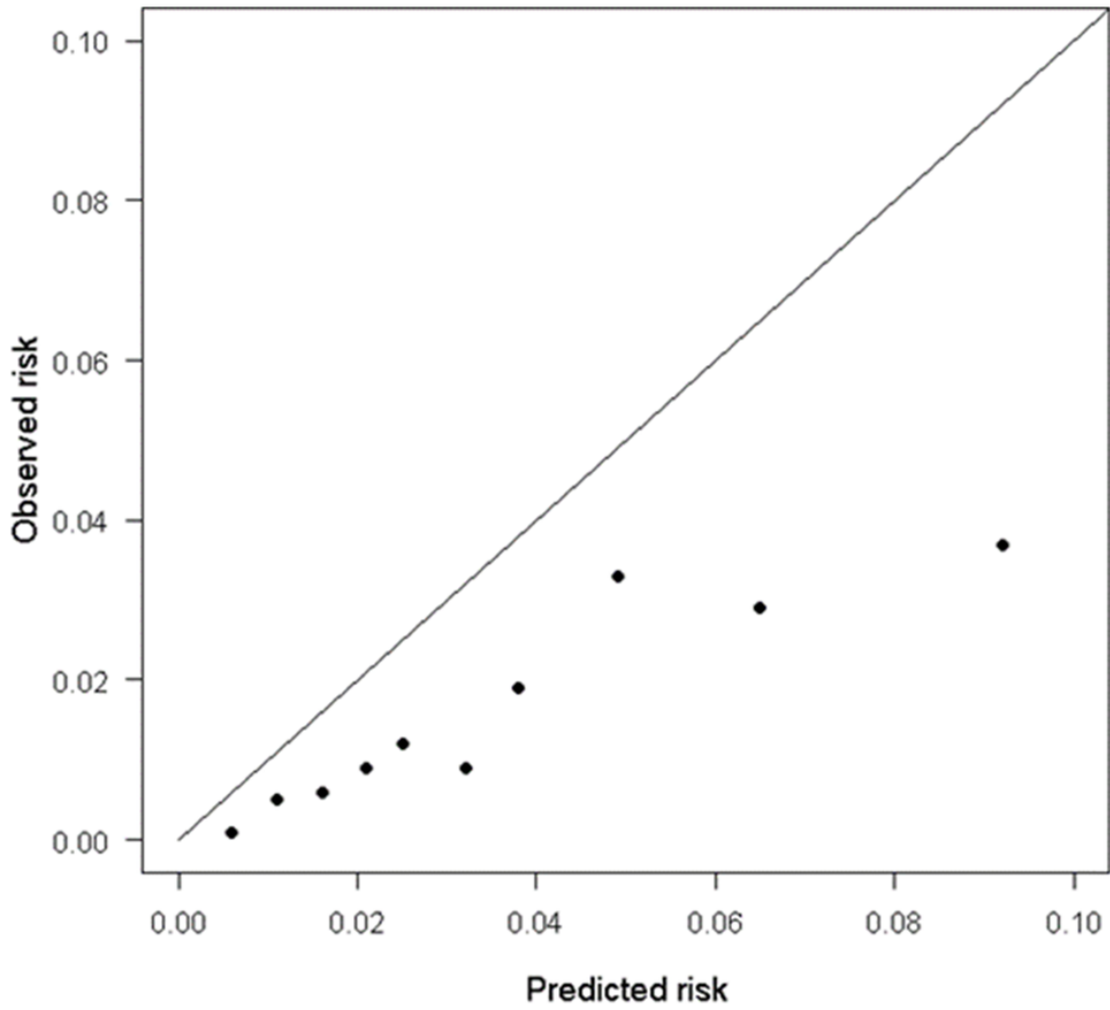


Figure 3
Comparison between observed risk and predicted risk of the stratified model by bedriddenness rank. A scatter plot of predicted risk on the horizontal axis and observed risk on the vertical axis.

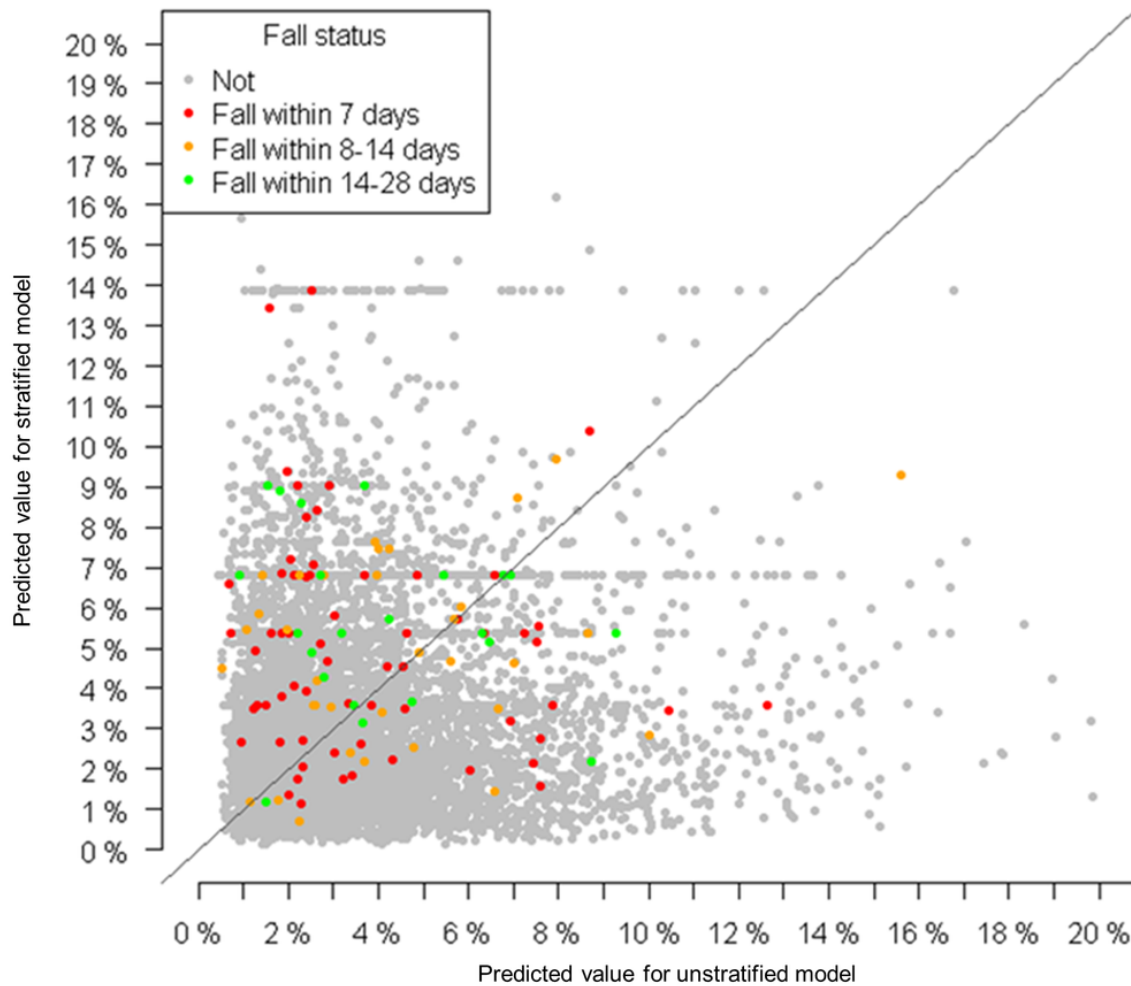


Figure 4

Comparison between predictive values of the stratified model by bedriddenness rank and the overall model without stratification. Gray: no falls; red: falls within seven days of admission; yellow: falls within 8–14 days of admission; green: falls within 14–28 days. Thus, the horizontal axis shows the predictive value for the overall Cox model without stratification. Further, and the vertical axis shows the corresponding predictive value for the Cox model with stratification by bedriddenness rank.

Supplementary Files

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- [20210806Supplementarymaterial.docx](#)