Decision support in hospital care for older patients

Medication, falls and delirium

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Performance assessment of the John Hopkins fall risk assessment tool in older hospitalized patients

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In submission

Abstract

Background: Fall prevention is a safety goal in many hospitals. The performance of the John Hopkins Fall Risk Assessment Tool (JHFRAT) in older inpatients is largely unknown. We aimed to assess the JHFRAT performance in a large sample of Dutch older inpatients. We studied the association of JHFRAT with inpatient falls, and the performance of the model based on JHFRAT in test accuracy, discrimination, and calibration. We also assessed the potential effect of time and of changes in population/healthcare needs due to seasonal influenza and COVID-19.

Methods: We used an Electronic Health Records (EHR) dataset with hospitalized patients (≥70), admitted for ≥24 hours between 2016-2021. We assessed associations between JHFRAT and falls by univariable logistic regression. For the test accuracy, we calculated the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). Discrimination was measured by the AUC. For calibration, we plotted the predicted fall probability with the actual probability of falls. We used ANOVA to compare the logistic model with and without adjusting for COVID-19 and seasonal influenza.

Results: The dataset included 17,263 admissions with ≥1 JHFRAT and a fall prevalence of 2.5%. JHFRAT and its subcategories were significantly associated with falls. For medium/high risk of falls (JHFRAT >5), the sensitivity was 73%, specificity 51%, PPV 4% and NPV 99%. The overall AUC was 0.67, varying over time between 0.62-0.71 (for 6 months' time intervals). The calibration was reasonable. COVID-19 and seasonal influenza did not affect the association between JHFRAT and falls.

Conclusions: Although our results show an association between JHFRAT and falls, the discrimination of JHFRAT for older inpatients was low, calibration showed over-prediction and thus further improvement is warranted. Future research can focus on developing fall-risk prognostic models using EHR data.

Introduction

Falling during hospital admission is a serious and common adverse event.[161] Approximately 3% of all patients and 5.9-6.4% of the patients 70 years and older fall during their hospital stay.[15,162] Falls can result in (severe) injuries, prolonged length of stay in the hospital and higher costs.[71,72,163] Fall-related injuries occurred in 26-42% of in-hospital falls and moderate/severe injuries in 8% of cases.[71,163] The length of stay and mean costs of patients with a fall-related injury are more than twice that of non-fallers.[72]

Improving prevention of in-hospital falls is a safety goal in many hospitals. The first step is to identify patients with a high risk of falling by screening all hospitalized patients for fall-risk factors. For patients with a medium or high fall risk, the treatment team subsequently starts interventions based on individual multifactorial assessment.[70] Interventions focus among others on medication, environment and mobility.[70]

For effective and efficient fall prevention, a tool that accurately predicts fall risk is of interest to healthcare workers and hospital management.[161] Several tools for the prediction of fall risk have been developed but the accuracy of these tools leaves room for improvement in predicting falls for older inpatients.[164,165] The John Hopkins Fall Risk Assessment Tool (JHFRAT) was developed in 2003 and published in 2005 as a tool applicable for all adult inpatients and aimed at a low workload for nurses.[166] Based on literature, a team (staff nurses, nurse educator, nurse manager, quality coordinator, clinical pharmacist, physical therapist) selected seven risk factors to be included in the tool. The team developed a scoring model, tested this model in potential patient scenarios and adjusted the scoring model based on group consensus.[166] In 2007, a post-implementation evaluation was published in which the tool was revised. The revision was based on literature and experiences of a committee of developers and nurses with experience in using the risk tool.[167]

To assess the performance of a prognostic tool, discrimination (how well does JHFRAT discriminate between non-fallers and fallers) and calibration (agreement of predicted probability to fall and actual fall probability) are important aspects.[168,169] Previously published studies assessed the discrimination of JHFRAT in a hospital setting. These studies were conducted in Korea, the US and Brazil.[170–172] None of the published studies on JHFRAT reported calibration, nor were they conducted in the EU and none studied the JHFRAT performance in a large older population.[164]

Furthermore, hospital populations and healthcare needs can change over time, for example due to more complex admitted patients, and during specific periods with changes in care demands such as seasonal influenza and COVID-19.[173–176] These changes could potentially impact the JHFRAT score and the actual occurrence of falls. A recently published paper showed that patients hospitalized due to seasonal influenza had a higher risk of fall-related injuries after hospitalization.[177] However, up to now none of the published studies on the performance of JHFRAT assessed the potential effect of these changes on the prognostic performance of JHFRAT.

Therefore, the objective of our study was to assess the performance of the JHFRAT in a population of older Dutch hospitalized patients using a large electronic health records (EHR) retrospective cohort. We studied the association of JHFRAT with inpatient falls, and the performance of the model based on JHFRAT in test accuracy, discrimination, and calibration. We also assessed the potential effect of time and of changes in population/healthcare needs due to seasonal influenza and COVID-19.

Methods

The reporting of this study follows the TRIPOD (transparent reporting of a multivariable prediction model for individual prognosis or diagnosis) reporting statement and a completed checklist can be found in Appendix A.[178]

Ethics approval

The Medical Ethics Review committee of Amsterdam UMC reviewed the study plan (reference number W18_027#18.043) and decided that according to the Medical Research Involving Human Subjects Act (WMO) approval was not needed.

Study population and data collection

The setting of our study was a university medical center with 1002 beds, located in the Netherlands (Amsterdam). The data was extracted from the EHR and included admissions of patients ≥70 years with at least 1 fall-risk score according to JHFRAT. If a patient fell during admission, only the JHFRAT before the fall was included. Patients needed to be admitted ≥24 hours between 2016-2021 (patients with admission dates between January 2016 and January 2021). We extracted data of medical diagnoses, age, admission/discharge dates, sex, medication administrations, JHFRAT (subcategory) scores, problem list and free text.

John Hopkins fall risk assessment tool

The fall-risk protocol in our hospital requires using the JHFRAT within 24 hours of each hospital admission (patients ≥18 years). The revised JHFRAT of 2007, contains 7 categories: age (0-3 points), fall history (0 or 5 points), elimination/ bowel/ urine (0, 2 or 4 points), medication (0, 3, 5 or 7 points), patient care equipment (0-3 points), mobility (0, 2, 4 or 6 points), and cognition (0, 1, 3 or 7 points). The highest possible total score is 35 points. The 2007 JHFRAT is used in the EHR of our hospital with one adjustment: all patients above 70 years get a risk-score of 2 points, in contrast to the 2007 JHFRAT in which patients 70-79 years get 2 points and patients ≥80 get 3 points. As in the 2007 JHFRAT, patients with a risk score >13 were rated as a high risk to fall, between 6-13 a medium risk and <6 a low risk. For patients with a medium or high fall risk, the hospitals' protocol advises starting a multifactorial assessment and individualized interventions based on the assessment in order to reduce the risk of falling.

Falls

In-hospital falls were extracted from the problem list and free-text data. Similar to our previous study, we created a regular expression using Dutch terms for falls and synonyms to identify falls in the problem list.[179] For the search in physician and nursing notes in free-text data, we used the program CTcue version 2.0.10.[180] In this program, we made two search queries and the patients identified by CTcue were manually reviewed by K.R., D.S. and M.D. to select the admissions with a fall. In case of doubt, the patients were also reviewed by B.D. We used the falls definition of the WHO: "A fall is an event which results in a person coming to rest inadvertently on the ground or floor or other lower level".[147] The free-text searches and regular expressions can be found in the appendix of our previous study.[179]

Statistical analysis

Prevalence of inpatient falls was expressed as the percentage of admissions with at least one fall during hospital stay. We used univariable logistic regression to investigate the association of the total score (continuous) of JHFRAT with inpatient falls. As total score is a continuous independent variable, we checked that it had a monotonous increasing relationship with falls. We also used univariable logistic regression to estimate the association between the different subscores of JHFRAT (all subcategories except for age, as all patients were >70 years and all had a score of 2) with inpatient falls.

As more than 50% of the admissions had a score of 0 for all subcategories, we decided to use a binary value ("yes" or "no") for each subcategory. To assess the change in JHFRAT score (compared to the 2007 JHFRAT) on the performance, we conducted a sensitivity analysis and gave all patients ≥80 1 additional point. We used generalized estimating equations in all logistic regression analyses to adjust for patients admitted multiple.

We calculated the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) of JHFRAT for two cut-off values: 1) cut-off value of >13 (high risk) and 2) cut-off value of >5 (medium or high risk). We applied the Wilcoxon rank sum test for the differences in median JHFRAT score between admissions with a fall and admissions without a fall. Subsequently, we used the area under the receiver operating characteristic curve (ROC_AUC) to quantify discrimination. We calculate the ROC_AUC for the whole time period (5 years), and per 6 months. The ROC_AUCs per 6 months were plotted to investigate the differences in ROC_AUC over time. Furthermore, we plotted the precision (PPV) -recall (sensitivity) curve which shows the PPV for different sensitivity thresholds.[181]. We also calculated the area under this curve (PR_AUC). This is a less commonly applied statistic to assess the performance of a prognostic model.

For the calibration of JHFRAT, we plotted the predicted probability of falling per admission against the actual probability of falls. To assess the potential effect of seasonal influenza or the COVID-19 pandemic in our analysis, we conducted two sensitivity analyses. For seasonal influenza, we compared the logistic model with JHFRAT total score to the logistic model with JHFRAT total score when adjusted for admissions during seasonal influenza periods ("yes" or "no"), as published by the Dutch national institute for public health and the environment, using ANOVA.[182] For COVID-19, we repeated the same sensitivity analysis but now for admissions during the COVID-19 period.

For all analyses, we used R-studio (version 1.3.1093) and a p-value of <0.05 as significant.

Results

Characteristics

In the period of 2016 – 2021 (5 years), 21,406 hospital admissions (≥24 h) were included in the database and 4143 were excluded (no completed JHFRAT).

Percentages of admissions with a filled-in JHFRAT varied between 74% and 89% per month. Table 6.1 shows the characteristics of the 17,263 admissions (11,947 unique patients) with ≥1 JHFRAT. In total, a fall occurred in 2.5% (427) of the admissions.

The median time to first fall was 6.2 days (IQR=2.6-14.2) and the median time to JHFRAT was 0.12 days (IQR=0.03 – 0.85). When comparing the total population (n=21,406) with the included population (n=17,263), more patients died in the total population (5% versus 3.4%).

Table 6.1. Patient characteristics and JHFRAT scores

	With Falls n=427	Without falls n=16,836	All admissions n=17,263
Patient characteristics			
Gender, % (n)			
Female	41% (173)	47% (7948)	47% (8121)
Male	59% (254)	53% (8888)	53% (9142)
Age, median (IQR)	77 (73-81)	76 (72-81)	76 (72-81)
Length of stay, median (IQR)	16.2 (8.1-31.1)	4.6 (2.1 – 8.7)	4.8 (2.1-9.0)
Number of medications, median (IQR)	24 (17-35)	17 (11-24)*	17 (11-24)*
Number of diagnoses, median (IQR)	9 (6-13)	5 (3-8)**	6 (3-8)**
Charlson score, median (IQR)	2 (1-4)	2 (0-3)**	2 (0-3)**
Died during admission, % (n)	9.6% (41)	3.3% (553)	3.4% (594)
JHFRAT			
Total score JHFRAT, median (IQR)	9.0 (5.0-13.5)	5.0 (2.0-10.0)	5.0 (2.0-10.0)
Low <6, % (n)	27% (114)	51% (8574)	50% (8688)
Medium risk JHFRAT 6-13, % (n)	48% (206)	38% (6476)	39% (6682)
High risk JHFRAT >13, % (n)	25% (107)	11% (1786)	11% (1893)

JHFRAT = John Hopkins Fall Risk Assessment Tool
* 106 NA ** 35 NA

Association of the subcategories of JHFRAT with inpatient falls

Table 6.2 shows the association of the JHFRAT with inpatient falls (OR=1.11 (1.03-1.20)). The total score of JHFRAT varied from 2-29. Table 6.2 also shows the association of subcategories of JHFRAT with falls. The admissions with a high fall-risk score had an OR of 4.5 (4.2-4.9) and admissions with a medium fall-risk score an OR of 2.4 (2.2-2.6) in comparison with the admissions with a low fall-risk score.

Table 6.2: Association of JHFRAT (sub)scores with inpatient falls using univariable regression analysis

	OR (CI 95%)	P-value
Total score (2-29)	1.11 (1.03-1.20)	<0.001
Fall history*	1.97 (1.83 – 2.12)	<0.001
Mobility*	2.83 (2.63 – 3.05)	<0.001
Cognition*	3.07 (2.86 – 3.31)	<0.001
Elimination, bowel and urine*	2.45 (2.28 – 2.64)	<0.001
Patient care equipment*	2.09 (1.94 – 2.25)	<0.001
Medications*	1.82 (1.69 – 1.95)	<0.001

* Binary value: "yes" or "no" (for example: "yes" (score>0) or "no" (score=0) for the subcategory cognition problems in the revised JHFRAT[167])

Test accuracy

For the cut-off value of >13, the JHFRAT had a sensitivity of 25%, specificity of 89%, PPV=6% and NPV=98% (Appendix B). For the cut-off value of >5, the JHFRAT had a sensitivity=73%, specificity=51%, PPV=4% and NPV=99%. For the cut-off value of >5, the 2007 JHFRAT as intended (with patients 80 years and older ranking 3 points) gave a sensitivity=74%, specificity=49%, PPV=4% and NPV=99%.

Discrimination

The median JHFRAT score in the group of admissions with inpatient falls was 9 points, and in the group without falls 5 points (Table 6.1). These groups were significantly different (<0.001). Figure 6.1 shows the ROC curve and the precision (PPV) - recall (sensitivity) curve. The ROC_AUC was 0.67 and the PR_AUC was 0.049. Figure 6.1b shows the PPV for each sensitivity and the three yellow dots give Sn=0.30, PPV=0.05 (dot 1), Sn=0.56, PPV=0.04 (dot 2), Sn=0.79, PPV=0.03 (dot 3).

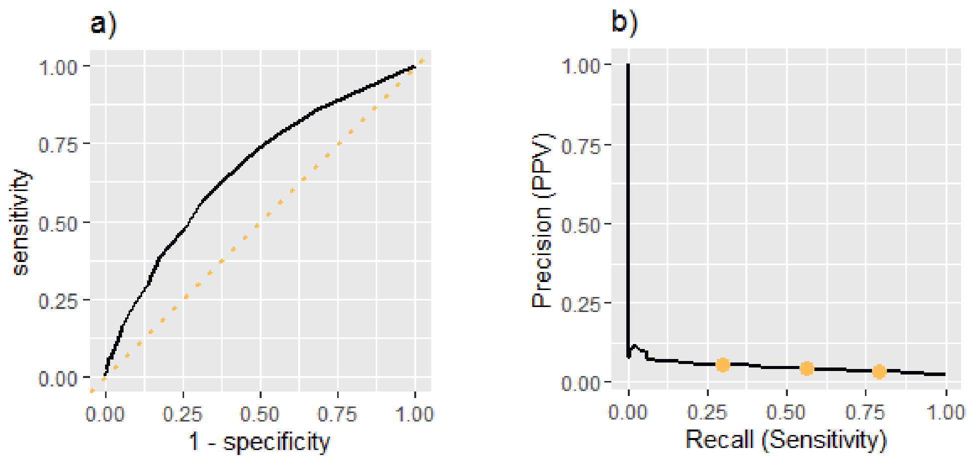

Figure 6.1. a) receiver operating characteristic (ROC) curve b) Precision (PPV) – recall (sensitivity) curve with yellow dot 1 (Sn=0.30, PPV=0.05), dot 2 (Sn=0.56, PPV=0.04), dot 3 (Sn=0.79, PPV=0.03).

The ROC_AUC (per 6 months) varied between 0.62 and 0.71 (Figure 6.2). The highest ROC_AUC (0.71) was observed in the period from July until December 2016. The lowest AUC_ROC (0.62) was observed in the period from July until December 2018.

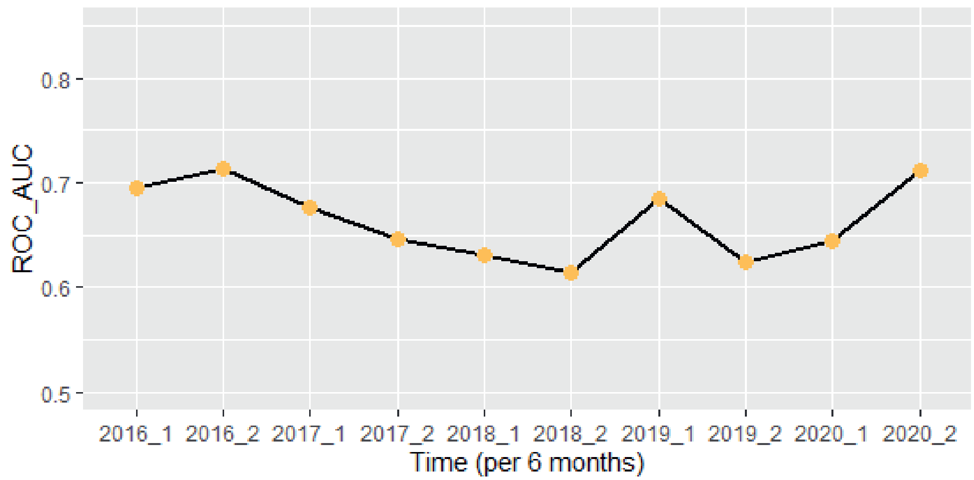

Figure 6.2. Area under the receiver operating characteristic curve (ROC_AUC) calculated per 6 months, plotted over time.

Calibration

Figure 6.3 shows the calibration plot with the predicted probability versus the actual probability of inpatient falls. The yellow-dotted line represents the perfect model performance. The black line represent actual calibration plot. Over-prediction is seen if the black line is under the yellow-dotted line. Under-prediction is seen if the black line is over the yellow-dotted line. Most admissions (16,919) had a predicted probability below 7,5%.

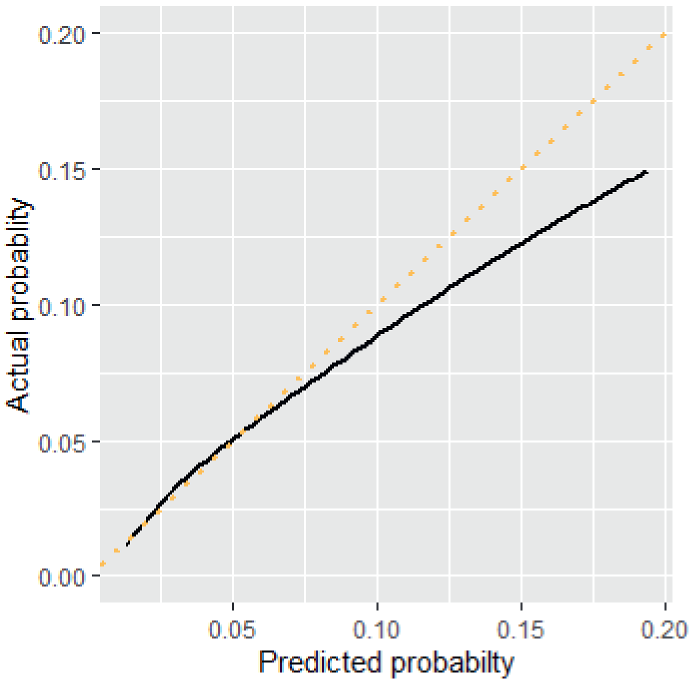

Figure 6.3. Calibration plot "predicted probability versus the actual probability"

Seasonal influenza and COVID-19

The model with adjusting for seasonal influenza was not significant (p = 0.07) better than the model without adjusting for seasonal influenza. The model with adjusting for COVID-19 was not significant (p = 0.11) better than the model without adjusting for COVID-19.

Discussion

Our study examined the performance of JHFRAT in a large population of older hospitalized Dutch patients. The results show that JHFRAT and subcategories of JHFRAT were significantly associated with in-hospital falls. Due to the study period of 5 years, we were able to assess the AUC over time. The overall AUC of JHFRAT was low and stable over time with an AUC varying between 0.62 and 0.71. The calibration of JHFRAT showed over-prediction. Our results did not show an effect of COVID-19 or seasonal influenza on the association between JHFRAT and falls.

Fall prevention in hospitals is important, especially for older patients, as fall prevalence rises with age. Assessing the risk of falls is a key step in fall prevention. Sufficient performance of a fall-risk tool is required in clinical practice. To the best of our knowledge, this is the first JHFRAT performance study in a large population of older hospitalized patients. Other studies assessed the performance of JHFRAT in patients aged 18 years and older.[170–172] One study conducted a sub-analysis to calculate the AUC in patients ≥65 years, with an unknown sample size of older patients (the sample size of patients ≥18 years was 1050). In a large EHR dataset, our analysis showed that of the JHFRAT subcategories cognitive problems had the highest association with falls, followed by mobility problems. One study assessed the association of JHFRAT subcategories with falls as well. The findings in this study were similar for 4/6 subcategories.[183] This study did not find an association between elimination problems or fall history on falls.[183] The differences with our study could be due to differences in population (patients ≥18 years vs ≥70 years), geography (Korea vs The Netherlands), study design (case-control 1:4 vs no case-control), falls detection system (adverse event reporting system vs detection through problem list and free text) or sample size (1050 patients vs 17,263 admissions). The association between JHFRAT and falls in our study was not affected by seasonal influenza or by the COVID-19 pandemic. The positive association of JHFRAT subcategories with falls implies these categories are important predictors for in-hospital falls, however, it does not imply causality.

According to our hospital protocols, fall-risk lowering interventions should be started in patients with a medium or high fall risk (JHFRAT >5 points). For this cut-off value, we found a sensitivity of 73% and a specificity of 51%. These fall within the broad ranges reported by previous studies in which the sensitivity ranged from 46% to 87% and specificity from 28% to 71%.[172,183]

These studies used a case-control study design and used a smaller sample size (~1000, vs ~17,000) compared to our study. A sensitivity of 73% implies that most of the admissions with a fall (73%) are identified using this cut-off value. However, still 27% of the admissions with a fall were not identified as having a medium/high fall risk. Preferably, the sensitivity of a fall-risk tool would be higher and more patients with a fall would be included in the medium/high-risk group without a substantial reduction in specificity.

We found a very low PPV of JHFRAT. The PPV reports the percentage of patients with a medium or high fall risk who actually did fall during admission.[184] The PPV depends on the fall prevalence in the population.[184] The PPV reported in our study is equal to the PPV (JHFRAT >13) of 4% found by Klinkenberg et al.[171] This study, conducted in the US, also used a retrospective chart review, but with 1.5% falls (our study: 2.5% falls). The PPVs reported by three other studies were much higher (PPV=34% to 41% for JHFRAT >13 and PPV=21% for JHFRAT >5).[170,183,185] These studies used a case-control design of 1:4 or 1:2 or reported a very high fall-incidence of 20%. This explains the high PPV, as the PPV depends on the prevalence of the outcome. Therefore the PPV in a case-control study cannot be used to estimate the PPV in practice. However, the very low PPV is problematic for the use of the JHFRAT in clinical practice as it hampers efficiency. Currently, only 4% of the admissions which should receive fall-risk decreasing interventions actually fall. There may however be an underestimation of the PPV due to misclassification, as the EHR dataset did not include fall-risk interventions and therefore it was not possible to determine whether the fall-risk intervention already prevented falls.

The AUC reflects the probability that JHFRAT correctly discriminates between admissions with and without a fall.[186] An AUC of 1 is excellent and a test with an AUC <0.5 is not useful.[187] Of the five previous studies reporting an AUC for the JHFRAT, one reported a lower AUC (0.58) and four reported higher AUCs (0.69, 0.70, and 0.71) compared to our AUC of 0.67.[170–172,183,188] One of these studies conducted a sub-analysis for patients ≥65 years and reported a lower AUC of 0.61.[183] Differences in the AUC might be explained by differences in the timing of performing the JHFRAT (first score during admission, last score before the fall/before discharge).[170–172,188] For example, in the study of Hur et al, the AUC of the first fall risk score was 0.63 and the AUC of the last fall risk score was 0.70. We conducted an extra sensitivity analysis to assess the effect of JHFRAT timing. In total, 14,323 admissions had a JHFRAT in the first 24 hours. The AUC in this group was 0.66 and therefore only slightly lower than the AUC in all patients with a JHFRAT.

Other differences between our study and previously published studies were differences in sample size, differences in fall incidence (1%-20%), in study design (prospective and retrospective cohorts or case-control), and differences in time period.[171,172,188] In our study, the AUC per 6 months varied between 0.62 and 0.71. The lowest AUC was found in the period from July -December 2018. This period included 1732 admissions, with a fall prevalence of 3.2%. The highest AUC was found in the period from July – December 2016. This period included 1712 admissions, with a fall prevalence of 2.8%. Except for fall prevalence (both higher than the overall fall prevalence of 2.5%), we did not find any differences in the patient characteristics between the groups in 2016 and 2018. The differences might be due or explained by situations or characteristics not included in our dataset or due to chance.

The results of our study increase knowledge on the performance of JHFRAT in a hospital setting. The sensitivity, the AUC and the PPV are low and leave room for improvement. Currently, all patients are manually screened by nurses. Our previous work reported that nurses preferred that information already known would be automatically filled in.[160] Administrative and clinical data offers opportunities for automatic fall-risk assessment without manual data entry.[157,189] Future research might focus on developing a prediction model using data already available in the EHR and/or requiring minimal additional data collection. Developed prediction models show promising first results.[188,190,191] A model using EHR data would diminish the workload of nurses and make this work process more efficient.

Strengths of our study were the use of a large dataset with hospital admission data over five years. This is the first study assessing the performance of the revised JHFRAT in the EU. Another strength is that we identified falls using not only the problem list but also free-text searches. We did, however, found a low overall fall prevalence compared to ~6% previously reported.[15,162,179] This might be due to falls not being documented in the EHR, or possibly only the more serious falls are being documented. It is also possible that our free-text search failed to detect some fall incidents. Limitations of our study are related to the retrospective study design. JHFRAT was used in practice and clinicians might have started interventions to reduce the risk of falls. This might have biased the results presented in our study. The results are, however, real-life results and therefore very relevant for clinical practice. Furthermore, a JHFRAT was not reported for all admitted patients.

The percentage of patients who died in the total population was higher (5%) than the population with JHFRAT (3.5%), implying that JHFRAT is completed less often in patients who have a high risk of in-hospital mortality.

Nurses stated in our previous study, that JHFRAT was not always filled in because of lack of time or other priorities.[160]

We conclude that in a large Dutch observational dataset, JHFRAT was associated with in-hospital falls and this association was not affected by seasonal influenza or by COVID-19. The discrimination between fallers and non-fallers was low, but stable over time. The calibration of JHFRAT showed over-prediction. Improvements in the fall-risk assessment are necessary to improve the efficiency of the workflow for nurses. Future research can focus on developing fall-risk prognostic models using EHR data or on improving the JHFRAT by automatically filling in already known information.