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Emergency department prediction model for 30-day mortality after hip fracture: the Spanish National Hip Fracture Registry (RNFC) cohort

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Abstract

Introduction: The aim of this study was to design and validate a predictive model for 30-day mortality in a cohort of patients from the Spanish National Hip Fracture Registry (RNFC) with variables collected at the Emergency Department.

Methods: Retrospective study of a prospective database of hip fracture patients ⩾75 years old between 1 January 2017 and 30 September 2019. Patient characteristics, type of fracture and osteoprotective medication were collected at the Emergency Department. Univariate analysis compared the results between patients alive and deceased 30 days after hospital discharge. The variables associated with 30-day mortality in the regression analysis were age >85 years, male sex, indoors pre-fracture mobility, dementia, ASA score >3, pathological fracture, and vitamin D intake. A score scale was created with these variables. Discriminative performance was assessed using the area under the curve (AUC), calibration was assessed by applying Hosmer-Lemeshow goodness-of-fit test and predicted-to-observed mortality was compared.

Results: A total of 29,875 hip fracture cases were included in the study. The 30-day mortality of the overall cohort was 7.7%. A scale of 0–9 points was created, with a cut-off point of 4 points for the determination of patients at high risk of mortality. The AUC was 0.886. RNFC score presented good level of calibration ($p = 0.139$). The predicted-to-observed ratio was 1.09.

Conclusions: The RNFC predictive model with variables collected at the Emergency Department showed an excellent predictive capacity for 30-day mortality in patients after hip fracture.

Keywords

Hip fracture, predictive model, scoring, 30-day mortality

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Introduction

Mortality after hip fracture remains high despite advances in patient management, anaesthetic, and surgical procedures.[1] Several studies indicate 3–5% in-hospital mortality, and 5–10% 30-day mortality.[2,3]

There are several predictive models for 30-day mortality after hip fracture published in available literature, which provide information on the variables associated with mortality with the aim to reducing it. ASA score, Charlson Comorbidity Index (CCI), Estimation of Physiologic Ability and Surgical Stress (E-PASS), Orthopaedic version of the Physiologic and Operative Severity Score for the enUmeration of Mortality and Morbidity (O-POSSUM), the model by Holt et al.,[4] and Nottingham Hip Fracture Score (NHFS) have been the most predictive models used to date. ASA score and CCI include subjective variables and have moderate discriminant capacity. E-PASS and O-POSSUM include variables which are not easy to obtain in daily practice. Holt et al.[4] used data from the Scottish Hip Fracture Audit and proposed a formula to calculate the predicted mortality based on preoperative variables. NFHS include variables collected at the Emergency Department and has demonstrated moderate discriminant capacity and acceptable calibration. Up to know, NFSH has showed the best predicted-to-observed ratio, and it is a model with extensive validation.[5–8]

The ideal predictive model must be precise, easy, and quick to apply, and based on information available before surgery. The early estimation of the prognosis of hip fracture could modify preoperative care, time of surgery or type of treatment. And this would influence the risk of mortality of these patients.

The National Hip Fracture Registry (RNFC) is a working group that has created a database with epidemiological, clinical, functional and care characteristics of patients ⩾75 years of age with hip fracture and follow-up 30 days after hospital discharge, at several hospitals in Spain. The objective is to apply this tool as an audit to improve quality of care for these patients. The RNFC started out with 10 hospitals in 2017 and now includes more than 80 hospitals. Data is submitted by the participating hospitals on a quarterly basis and an annual report is published, which can be consulted on the registry website (http://rnfc.es). The design and validation of a predictive model for mortality is one of the RNFC objectives.

The aim of this study was to design and validate a predictive model of 30-day mortality after hip fracture with the RNFC variables available at the emergency department. We compared our model with NFHS and Holt et al.[4] predictive models. Our hypothesis was that RNFC model would have a similar ability to discriminate patients as the NFHS and Holt et al.[4] predictive models.

Material and methods

Study design

Retrospective study of the RNFC database between 01 January 2017 and 30 September 2019. The criteria for inclusion in the study were aged ⩾75 years, suffering a fragility hip fracture, and providing consent given for inclusion in the study. The study protocol was approved by the Ethics Committee in the hospitals with the highest volume of patients included in the registry. Spanish legislation allows approval to be expanded to other Spanish hospitals for multicentric studies. Patients were divided into 2 groups: model design cohort and model validation cohort. The model design cohort comprised patients enrolled in the registry in the first ½ of each year, while the model validation cohort comprised patients enrolled in the registry in the second ½ of each year.

Study variables

The Spanish adaptation of Fragility Fracture Network's 2014 Minimum Common Dataset,[9] was collected for each patient. Preoperatively, the following variables were recorded: age at the time of fracture, sex, pre-fracture residence (home or care home); pre-fracture mobility on a scale of 1–10: independent mobility indoors and outdoors without technical aids (Grade 1), independent mobility indoors and outdoors with one technical aid (Grade 2), independent mobility indoors and outdoors with 2 technical aids or walker (Grade 3), independent mobility only indoors without technical aid (Grade 4), independent mobility only indoors with 1 technical aid (Grade 5), independent mobility only indoors with 2 technical aids or a walker (Grade 6), independent mobility only indoors under supervision (Grade 7), mobility only indoors with little assistance from a person (Grade 8), mobility only indoors with great assistance from a person (Grade 9), mobility with 2 persons or no mobility (Grade 10); cognitive level using Pfeiffer's Short Portable Mental Status Questionnaire adapted to Spanish,[10] with a threshold of cognitive impairment at >3 errors; type of fracture (non-displaced intracapsular, displaced intracapsular, intratrochanteric and subtrochanteric), and whether it was pathological or not; use of osteoprotective medication (before to the fracture, at discharge and at 30 days); and anaesthetic risk using the American Society of Anesthesiologists (ASA) score.[11] The method of treatment (surgical/nonoperative) was recorded, as well as the type of surgery, the type of anaesthesia (spinal/general, use of a nerve block) and the surgical delay in hours were also collected for the cases managed surgically. Variables collected postoperatively included multispecialty clinical management (participation of geriatrics or internal medicine) during hospital admission; mobilisation on the first postoperative day, weight-bearing recommendations; development of pressure ulcers; length of hospital stay (days); discharge destination (home or residence); 30-day survival and the need for readmission or reoperation within 30 days were also noted.

Outcome variable

The primary outcome variable of the study was the patient's vital status 30 days after hospital discharge.

Statistical analysis

Statistical analysis was performed using SPSS version 21.0 software (SPSS Inc., Chicago, IL, USA).

The Kolmogorov-Smirnov test found that the quantitative variables did not follow normality criteria and were therefore presented with the median and interquartile range (IQR). Analysis of missing data showed 2 variables with percentages $>1\%$: cognitive status with 17.4% and ASA score with 19.4%. Several variables were recoded: age into $\geqslant 85$ years; pre-fracture mobility into whether patients walked outdoors (Grade 1–3) or not (Grade 4–10); fracture type into intracapsular (displaced or non-displaced) or extracapsular (intertrochanteric and subtrochanteric); ASA score into <III or ⩾III.

Univariate analysis using the chi-square test for qualitative variables, and the Mann-Whitney U-test for quantitative variables compared the results between patients alive and deceased 30 days after hospital discharge.

To determine the relationship between the 30-day vital status (alive/deceased) as the dependent variable and the significant independent variables found in the univariate analysis, binary logistic regression analysis was performed using the forward stepwise method with likelihood ratios.[12] Cases with missing values for the independent variables were eliminated before performing binary logistic regression analysis and not included in the model. Coefficients and odds ratios (ORs) with 95% confidence interval (CI) were obtained. Statistical significance was determined at a value of $p < 0.05$. Variables significantly associated with 30-day mortality in the regression analysis were used to create a score. The coefficient obtained for each variable was multiplied by 2 and rounded to the nearest whole number. The ROC curve with the maximum Youden index was used to determine the cut-off point for best estimating the probability of 30-day mortality.[13] The model's goodness of fit was analysed with the Hosmer-Lemeshow coefficient and the c-statistic, equivalent to the area under the curve.[14] As a rule of thumb, a value of c between 0.70 and 0.79 is considered acceptable, and between 0.80 and 0.89 is considered excellent.[15]

Results

A total of 29,875 patients with hip fractures were included in the registry between 2017 and 2019. According to date of inclusion in the registry, patients were distributed into the model design cohort (16,427 hip fractures) and the model validation cohort (13,448 hip fractures).

The overall 30-day mortality in the entire cohort was 7.7% (2321 patients).

Model design cohort

In the model design cohort, 1282 patients (7.8%) had died within 30 days after the hip fracture. The characteristics of the patients in the design cohort with the results of the univariate analysis of 30-day mortality are shown in Table 1. 17 statistically significant variables were found in the univariate analysis. From these, the variables available at Emergency Department were selected, reducing the number of variables to 10. Multivariate analysis on 10,355 hip fractures identified 7 variables as independent predictors of 30-day mortality after hip fracture: age, gender, pre-fracture mobility, dementia, ASA score, pathological fracture, osteoprotective medication. The scoring scale of the model ranged from 0 to 9 points (Table 2). The model equation for the calculation of the 30-day mortality probability after hip fracture was:

$$
\begin{aligned}
&\text{Logit}\left(30-\text{day mortality}\right) = -4.782 \\
&+\left(0.533 \text{ x age} > 85\right) + \left(0.726 \text{ x sex male}\right) \\
&+\left(0.737 \text{ x pre}-\text{fracture mobility} > 3\right) \\
&+\left(0.434 \text{ x Pfeiffer} > 3\right) \\
&+\left(0.913 \text{ x ASA} >= 3\right) \\
&+\left(0.985 \text{ x pathological fracture}\right) \\
&+\left(0.29 \text{ x VitaminDno}\right)
\end{aligned}
$$

The goodness-of-fit coefficient of the model reached 0.886, and the Hosmer-Lemeshow test showed no significant lack of fit ($p = 0.139$). Based on the ROC curve, a cut-off of 4 points on the scale was determined to identify patients at high risk of 30-day mortality post hip fracture (Figure 1).

Table 3 indicates the predicted 30-day mortality rate after hip fracture according to the RNFC model scale.

Model validation cohort

In the model validation cohort, 1039 patients (7.7%) had died within 30 days after the hip fracture. Patient characteristics were like those of the design cohort (Table 4). The model was applied to 8516 fractures selected randomly.

Table 1. Univariate analysis of 30-day mortality in the model design cohort.

	Alive n = 14,521	Deceased n = 1282	p
Age (years)*	86 (82–90)	89 (85–93)	<0.001
Age >85	8279 (57.0)	945 (73.7)	<0.001
Sex			
Female	11,161 (76.8)	801 (62.4)	<0.001
Male	3360 (33.2)	481 (37.6)	
Pre-fracture residence			
Own (private= home)	11,060 (76.1)	861 (67.1)	<0.001
Skilled care facility	3399 (23.9)	405 (32.9)	
Pre-fracture mobility			
Levels 1 to 3 (outdoors mobility)	7985 (54.9)	380 (29.6)	<0.001
Levels 4 to 10 (indoors only or no mobility)	6401 (44.1)	877 (70.4)	
Cognitive status (Pfeiffer's Short Portable Mental Status Questionnaire)			
Pfeiffer's score*	3 (0–6)	5 (2–8)	<0.001
Pfeiffer score > 3 errors	5212 (35.8)	607 (47.3)	0.001
Fracture type			
Intracapsular	5,751 (39.6)	493 (38.4)	0.24
Extracapsular	8,755 (60.4)	784 (61.6)	
Pathological fracture	129 (0.8)	29 (2.2)	<0.001
Pre-fracture osteoprotective treatment			
Yes	875 (6.0)	51 (3.9)	0.002
Antiresorptives	798 (5.4)	40 (3.1)	0.001
Osteoforming drugs	104 (0.7)	6 (0.4)	0.36
Calcium	1720 (11.8)	116 (9.0)	0.002
Vitamin D	2642 (18.0)	180 (14.0)	0.001
ASA category.			
I-II	1681 (11.5)	54 (4.2)	<0.001
III-IV-V	9948 (88.5)	1056 (95.8)	
Management during hospital admission			
Surgical delay (hours)*	52.5 (26.8–90.9)	66.8 (37.7–105.2)	<0.001
Delay >48 hours	7356 (52.5)	610 (61.8)	<0.001
Spinal anaesthesia	13,161 (90.6)	889 (69.3)	0.02
Nerve block	1968 (13.5)	154 (12.0)	0.35
Clinical specialist involved	13,967 (96.1)	1226 (95.6)	0.82
Mobilised 1st postoperative day	9343 (64.3)	424 (33.0)	0.001
Weight-bearing not permitted	520 (3.5)	34 (2.6)	0.01
Pressure sores newly developed	797 (5.4)	133 (10.3)	0.001
Length of stay (days)*	8.8 (6.5–12.2)	9.4 (6.4–14.2)	0.12
Hospital discharge			
Own (private) home	6,244 (43.3)	358 (27.9)	0.001
Skilled care facility/geriatric recovery unit	8,277 (56.7)	924 (72.1)	<0,001
Readmission <30 days	549 (3.7)	79 (6.1)	0.001
Reoperation <30 days	318 (2.1)	11 (0.8)	0.54

*Median (interquartile range); all other variables are presented with *n* (%).

The median score for the series was 6 points (IQR 5–7). Deceased patients had significantly higher median score of 7 points (IQR 6–8) compared to 5.9 (IQR 5–7) in surviving patients ($p < 0.001$). 87.6% (7463 patients) were categorised as high-risk patients and 12.4% (1053 patients) as low-risk patients. The mortality rate in high-risk patients was significantly higher than in low-risk patients (8.8% vs. 1.6%; $p < 0.001$). The odds ratio for 30-day mortality from hip fracture due to belonging to the high-risk group was 5.84 (95% CI, 3.67–9.21). The sensitivity of the model in the validation cohort was 97.5%, specificity 13.2%, positive predictive value 8.8% and negative predictive value 98.4%. The consistency between the expected and 30-day mortality percentage observed is shown in Figure 2.

Table 2. Independent factors present at admission predictive of 30-day mortality in multivariate analysis and scoring of each variable for inclusion in the RNFC predictive model.

	Coefficient	*p*	Odds ratio	95% CI	Score
Age >85 years = YES	0.533	0.001	1.70	1.44–2.0	1
Sex = Male	0.726	0.001	2.06	1.77–2.41	1
Pre-fracture mobility >3 = YES	0.737	0.001	2.08	1.76–2.47	1
Pfeiffer >3 = YES	0.434	0.001	1.54	1.31–1.81	1
ASA III-IV-V = YES	0.913	0.001	2.49	1.81–3.41	2
Pathological fracture = YES	0.985	0.001	2.67	1.59–4.51	2
Vitamin D = No	0.290	0.007	1.33	1.08–1.65	1

CI, confidence interval.

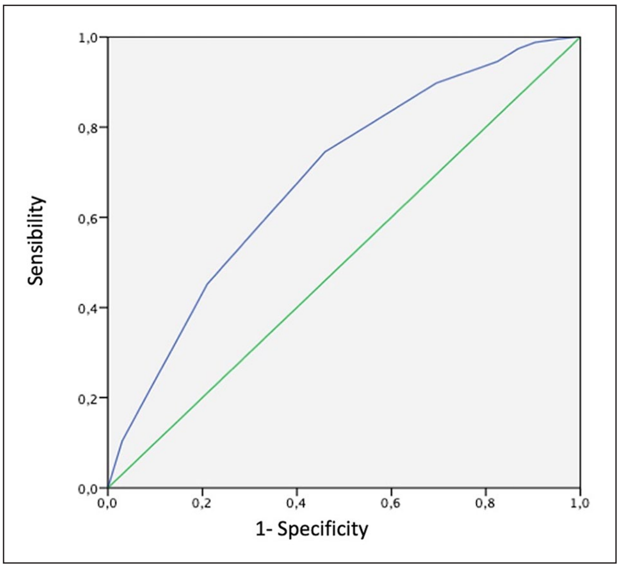

Figure 1. ROC curve of 30-day mortality after hip fracture derived from the RNFC predictive model.

Discussion

We developed and validated a predictive scoring model for 30-day mortality after hip fracture patients ⩾75 years old. The RNFC model incorporates age, gender, pre-fracture mobility, dementia, ASA score, pathological fracture, and vitamin D intake. The value of the model's c-statistic of 0.886, good level of calibration ($p = 0.136$), and the predicted-to observed ratio was 1.09. According to RNFC model, the higher the score, the higher the predicted probability of mortality.

30-day mortality in our cohort was 7.7% (2321 patients) and was comparable to other studies. Nia et al.[8] report a 30-day mortality of 6.1% in their cohort of 1101 hip fractures, Van Rijckevorsel et al.[16] 7.9% in 2458, Karres et al.[5] 8.2% in 1050, Haugan et al.[17] 7.5% in 3651, Maxwell et al.[6] 7.8 in 4967, and in 2020, the Royal College of Physicians National Hip Fracture Database reported a 6.5% mortality in 67,302 patients.[18]

Only 2 predictive models of 30-day mortality have been specifically developed for hip fracture patients. Maxwell et al.[6] published the NHFS (Nottingham Hip Fracture Score) using multivariate logistic regression in a cohort of 4967 hip fractures. The variables included in the model were age, sex, number of comorbidities, mini-mental test, haemoglobin level on admission, place of residence and presence of malignancy in the past 20 years, and a score was created from these variables. The value of the model's c-statistic was 0.79.[5] Holt et al.[4] proposed a multivariate logistic regression model in a cohort of 18,817 from the Scottish hip fracture audit. The variables in the model were age, sex, ASA score, pre-fracture residence, pre-fracture mobility and fracture type. With these variables, they developed a formula to calculate the probability of mortality. The value of the model's c-statistic was 0.76.[18] Karres et al.[5] evaluated 6 predictive models of 30-day mortality in a cohort of 1050 hip fractures. The models with the best discrimination value were those designed specifically for hip fracture patients (NHFS and Holt).[4] Recently, Pallardo et al.[7] published a review of models that stratify the risk of mortality after hip fracture and concluded that the NHFS is the simplest and quickest to apply and can be used at the emergency department.

The RNFC model is based on 7 variables collected at the Emergency Department. The score can be easily calculated, and noted in the patient's medical record. The c-statistic value was 0.886, which is considered excellent. The sensitivity and negative predictive value were high. It allows the detection of patients at high-risk for 30-day mortality. The expected mortality according to the model was close to the observed mortality, with a mean value of the ratio of 1.09. The NFHS is an excellent score to predict 30-day mortality. It had been developed and validated to predict risk in patients undergoing surgery for fractured neck of femur.[5] Subsequently, it has been validated extensively in hip fracture cohorts.[4,6,7]

RNFC model include 3 variables (age, gender, and dementia) that are also use in NFHS. The other 4 variables (pre-fracture mobility, ASA score, pathological fracture,

Table 3. Expected 30-day mortality rate after hip fracture according to RNFC model scoring scale.

	Average	Standard deviation	95% CI	Minimum	Maximum
Zero	0.850	0.16	0.810–0.890	0.83	2.19
One	1.118	0.17	1.164–1.198	1.10	2.91
Two	2.068	0.43	2.030–2.107	1.69	5.83
Three	3.565	0.73	3.489–3.640	2.86	9.64
Four	3.996	0.24	3.808–4.183	2.04	8.68
Five	3.230	1.37	3.155–3.305	2.71	11.27
Six	5.266	1.28	5.215–5.318	4.12	16.59
Seven	8.901	1.90	8.829–8.973	6.83	24.39
Eight	14.191	2.22	14.091–14.290	13.16	38.81
Nine	24.276	2.21	24.054–24.498	24.05	45.89

CI, confidence interval.

Table 4. Characteristics of patients in the model validation cohort.

	Alive *n* = 13,448	Deceased *n* = 1282	*p*
Age (years)*	86.7 (83 - 90)	89.5 (85 - 93)	<0.001
Age >85 years	8279 (57.0)	945 (73.7)	<0.001
Sex			
Female	11,161 (76.8)	801 (62.4)	<0.001
Male	3360 (33.2)	481 (37.6)	
Pre-fracture residence			
Own (private = home	11,060 (76.1)	861 (67.1)	<0.001
Skilled care facility	3399 (23.9)	405 (32.9)	
Pre-fracture mobility			
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Cognitive status (Pfeiffer's Short Portable Mental Status Questionnaire)			
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Pfeiffer score >3 errors	5212 (35.8)	607 (47.3)	0.001
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Weight-bearing not permitted	520 (3.5)	34 (2.6)	0.01
Pressure sores newly developed	797 (5.4)	133 (10.3)	0.001
Length of stay (days)*	8.8 (6.6–2.1)	9.3 (6.2–13.7)	0.16

(Continued)

Table 4. (Continued)

	Alive $n = 13{,}448$	Deceased $n = 1282$	p
Hospital discharge			
Own (private) home	6244 (43.3)	358 (27.9)	0.001
Skilled care facility / geriatric recovery unit	8277 (56.7)	924 (72.1)	<0,001
Readmission <30 days	549 (3.7)	79 (6.1)	0.001
Reoperation <30 days	318 (2.1)	11 (0.8)	0.54

*Median (interquartile range); all other variables are presented with *n* (%).

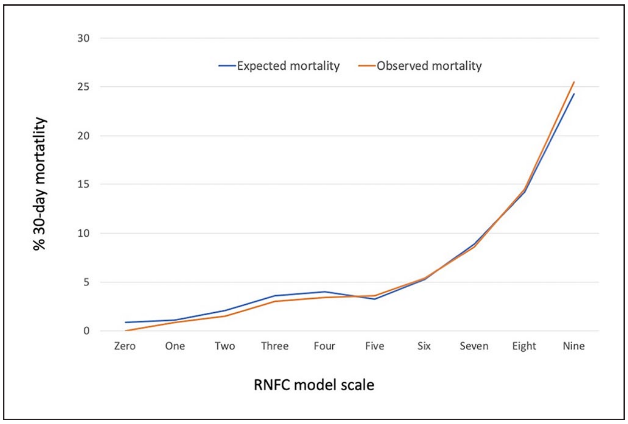

Figure 2. Concordance between the percentages of expected mortality and observed mortality at 30 days after hip fracture according to the RNFC predictive model.

and osteoprotective medication) are not included in NFHS. The model by Holt et al.[4] to predict 30-day mortality is based in a large study sample. However, no analysis of its predictive performance is reported, nor has it been validated in consequent studies.[8] RNFC model include 4 variables (age, gender, ASA score, pre-fracture mobility) that are also use in this model. The other 3 variables (dementia, pathological fracture, and osteoprotective medication) are not included in this model. Our model did not include type of fracture, so that we did not find statistically significant differences of mortality between intracapsular and extracapsular hip fractures in univariate analysis. Pre-fracture place of residence reached statistically significant differences of mortality in univariate analysis. However, it was not identified as independent predictors of 30-day mortality after hip fracture in the multivariate analysis. RNFC score presents certain similarities with NFHS score and the model by Holt et al.,[4] however, with a slightly superior c-statistic.

Our study does, however, present some limitations. This is a retrospective study on a prospectively collected database in which 2 variables have a missing case rate over 1%. Intraoperative or postoperative variables considered predictors of mortality after hip fracture are not included either. The model is not valid for hip fracture patients <75 years of age.

It also presents certain strengths. It is a national survey with a broad territorial representation. The RNFC patients are similar to hip fracture patients in Spanish hospitals collected through the Health Ministry's Minimum Basic Dataset (CMBD) that collects information on all episodes admitted to hospital nationally, raising the possibility of extrapolating this predictive model to a national level.[19] Patients were divided into 2 groups, 1 for model design and 1 for validation. The sample size is sufficient for developing a predictive model. The model has been developed specifically for hip fracture patients; it is simple, straightforward, easy to use, and information can be obtained directly at the emergency department and added to the patient's medical record.

Conclusion

The RNFC predictive model is an easy tool with an excellent predictive capacity, and no significant lack of fit for 30-day mortality in patients >74 years old after hip fracture. It allows to discriminate between patients at high-risk and low-risk for 30-day mortality at the Emergency Department. RNFC score presents a slightly superior c-statistic compared with NFHS score and the model by Holt et al.[4]

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Supplemental material

Supplemental material for this article is available online.

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