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Combining the Hospital Frailty Risk Score With the Charlson and Elixhauser Multimorbidity Indices to Identify Older Patients at Risk of Poor Outcomes in Acute Care

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Objective: The Hospital Frailty Risk Score (HFRS) can be applied to medico-administrative datasets to determine the risks of 30-day mortality and long length of stay (LOS) in hospitalized older patients. The objective of this study was to compare the HFRS with Charlson and Elixhauser comorbidity indices, used separately or combined.

Design: A retrospective analysis of the French medical information database. The HFRS, Charlson index, and Elixhauser index were calculated for each patient based on the index stay and hospitalizations over the preceding 2 years. Different constructions of the HFRS were considered based on overlapping diagnostic codes with either Charlson or Elixhauser indices. We used mixed logistic regression models to investigate the association between outcomes, different constructions of HFRS, and associations with comorbidity indices.

Setting: 743 hospitals in France.

Participants: All patients aged 75 years or older hospitalized as an emergency in 2017 (n = 1,042,234). Main outcome measures: 30-day inpatient mortality and LOS > 10 days.

Results: The HFRS, Charlson, and Elixhauser indices were comparably associated with an increased risk of 30-day inpatient mortality and long LOS. The combined model with the highest c-statistic was obtained when associating the HFRS with standard adjustment and Charlson for 30-day inpatient mortality (adjusted c-statistics: HFRS = 0.654; HFRS + Charlson = 0.676) and with Elixhauser for long LOS (adjusted c-statistics: HFRS = 0.672; HFRS + Elixhauser = 0.698).

Conclusions: Combining comorbidity indices and HFRS may improve discrimination for predicting long LOS in hospitalized older people, but adds little to Charlson's 30-day inpatient mortality risk.

Key Words: comorbidity, frailty, statistics and numerical data, mortality, length of stay

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With an aging population, ever more older patients with complex multimorbidity and frailty present to acute care hospitals,[1–4] which imposes a shift toward a more holistic approach to hospital care away from the ultraspecialized model focused on single conditions.[5] The complex interplay between different conditions is a problem that is often exacerbated in the aging population. Both multimorbidity and frailty increase with age, and it can sometimes be difficult to distinguish these two concepts.[6,7]

Multimorbidity, as defined by at least 2 chronic diseases, affects around 70% of patients aged 75 years and over, while <10% of people in this age group have no disorder reported.[1] The term "comorbidity," sometimes used interchangeably, can be distinguished as the co-occurrence of one or more conditions with reference to an index condition of interest.[8] Multimorbidity becomes prevalent from the fifth decade of life and continues to increase with age, while frailty becomes more prevalent in later life.[7] In the older population, the multimorbidity model for risk prediction is increasingly being supplanted by models based on the more integrative concept of frailty, which may better capture the needs of older individuals.[9–11]

Frailty can be defined as a state of increased vulnerability of older patients toward adverse outcomes when exposed to a stressor event.[12] Because of variable operational approaches, its prevalence is more difficult to estimate, but frailty likely affects more than 30% of people in this age group.[3,13]

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The current development of electronic health records and technological advances in storing and processing big data represents a major opportunity to better inform on the complexity of older patients' care.[14,15]

Several methods have been suggested to operationalize frailty from electronic health records,[15] either by highlighting geriatric syndromes,[16] creating frailty indices,[17–20] or clustering patterns of hospital care resource use. The Hospital Frailty Risk Score (HFRS)[21] has been validated in several countries to predict mortality and prolonged length of stay (LOS) of older hospitalized patients.[22–25] On French medico-administrative data, the HFRS discriminates fairly inpatient mortality and prolonged LOS (c-statistics of adjusted models of 0.676 and 0.684, respectively) with excellent model calibration.[25]

The HFRS may be used for risk stratification and service planning, or as a marker of frailty in epidemiological studies. However, as this score is constructed exclusively on diagnostic codes from the ICD-10 nomenclature, this raises the question of a possible interaction or overlap with the more general concept of multimorbidity.[7,26] Hence, it is important when using administrative data to disentangle HFRS from the recognized Charlson and Elixhauser multimorbidity indices.[27–29]

The aim of this study was to establish whether the HFRS is able to discriminate patients with the risks of poor outcomes among hospitalized older patients over and above the Charlson[27] and Elixhauser[29] multimorbidity indices. Also, in the same way that combining comorbidity indices might improve the accuracy of risk stratification,[30,31] we sought to explore possible combinations and overlaps of the HFRS with these multimorbidity indices.

METHODS

Study Design and Participants

This study was conducted using the same cohort as the previously published validation study of the HFRS in metropolitan France.[25] We conducted a retrospective analysis of anonymized secondary care data from the French nationwide Medical Information System [*Programme de Médicalisation des Systèmes d'Information* (*PMSI*)*, source: ATIH*] database, which contains routinely collected data from electronic health records of all public and private hospitals in France (Trial Registration: reference ID on clinicaltrials.gov: ID: NCT03905629). We included all patients aged 75 years and older (on the day of the index admission) hospitalized as an emergency over a period of 1 year between January 1 and December 31, 2017. In case of multiple admissions of the same patient, the patients were only included once, considering the first (index) admission.

Data Collection

The outcomes were in-hospital mortality within 30 days from the beginning of the index admission and long LOS (>10 days). In-hospital mortality was collected even if it occurred during a readmission. Long LOS was defined as >10 days, in line with the initial validation study of the HFRS score in the United Kingdom.[21]

Patient covariates included age, sex, and admission history (ie, the number of hospital bed-days during the past 2 years from the index admission as a continuous variable and, for descriptive purposes only, the number of previous admissions in this period). Patients' socioeconomic status (median household income in the city of residence, continuous) and medical accessibility (mean number of family medicine consultation/year/inhabitant in the city of residence, continuous) were associated with patients' city of residence postcode and provided by the National Institute of Statistics and Economic Studies. Territorial factors considered included primary care access evaluated by accessibility to general practitioners, and region of residence of patients. The hospital status (university hospital, regional, or local hospital, private for-profit hospital) was retrieved for each index hospitalization.

HFRS and Comorbidity Indices

The HFRS was calculated for each patient, based on the ICD-10 diagnoses documented in their index emergency admission and hospital records, and retrieved from anonymized discharge summaries, going back 2 years in compliance with the original validation study.[21] Patients were allocated to 1 of 3 categories based on their HFRS score (low risk <5, intermediate risk 5–15, high risk >15).

Charlson and Elixhauser comorbidity indices were calculated for each patient according to the standard published methodologies.[32,33] These 2 indices have acceptable validity in French databases.[34] To ensure comparability with HFRS, both indices drew on diagnostic information from the index admission and any admission in the preceding 2 years. To allow comparison with the 3 categories of HFRS, both indices were categorized in 4 categories with Charlson groups 0, 1, 2, or ≥ 3 (as in Gilbert et al[21]) and the Elixhauser groups 0–1, 2–3, 4–5 or ≥ 6 (thresholds determined according to the quartiles).

We considered diagnostic information from the patient's index admission and those occurring in the previous 2 years to build "standard" HFRS, Elixhauser, and Charlson comorbidity indices. The details of ICD-10 codes used to construct HFRS and each comorbidity index are presented in Appendix 1, Supplemental Digital Content 1, http://links.lww.com/MLR/C774.

Statistical Analysis

Patient characteristics used as adjustment factors were described using means and standard deviations for continuous variables, and number and percentages for categorical variables. Correlations between HFRS and either Elixhauser or Charlson comorbidity indices were assessed with Spearman's rank correlation coefficient. Correlation was considered weak above 0.10, moderate above 0.40, and strong above 0.70.[35]

We estimated the association of the HFRS categories with outcomes using mixed logistic regression models with random effects to capture hospital variation.[25] Models were systematically estimated with a basic adjustment on patient case-mix (ie, age, sex, socioeconomic data, and admission history), and on either Charlson or Elixhauser indices. Associations between (i) HFRS categories, (ii) Charlson's

index categories, and (iii) Elixhauser categories, and each outcome was evaluated with odds ratios, accompanied by 95% CIs. Model discrimination was assessed through obtained c-statistics. A full specification of each model is available in Appendix 2, Supplemental Digital Content 1, http://links.lww.com/MLR/C774. We also excluded information from the index admission to build "historic" scores to assess its impact on model discrimination.

While some diagnosis codes are unique to each score (eg, W06 "fall involving bed" is specific to HFRS), others are common across measures (eg, K26 "duodenal ulcer" is used in all 3) (Appendix 1, Supplemental Digital Content 1, http://links.lww.com/MLR/C774). Hence, there might be a correlation between HFRS and comorbidity proxies. To deal with this concern, we defined different partitions of HFRS according to the overlapping of its ICD-10 diagnostic codes with Charlson and Elixhauser comorbidities. By excluding either Charlson or Elixhauser comorbidities from the HFRS, we created 2 subscores of HFRS (HFRSminC and HFRSminE), respectively, aimed to be associated with Charlson or Elixhauser comorbidity indices, to find the best combination for risk stratification. Model interactions between frailty and comorbidity indices were also tested. Finally, we performed a sensitivity analysis using each score or index as continuous variables using splines and functional forms to model their association with outcomes.

Data manipulation and analyses were performed using SAS software (version 9.4; SAS Institute Inc.).

RESULTS

The cohort of 1,042,234 patients aged 75 years and older hospitalized as an emergency in 743 hospitals in France has been described previously.[25] Summary statistics for the outcomes, adjustment factors, and the 3 comorbidity or frailty indices are presented in Table 1. High-risk patients according to the HFRS had overall increased Charlson and Elixhauser indices and were more likely to die or to have a long LOS (>10 days).

HFRS had 13.8% (15/109) ICD-10 codes in common with the Charlson index and 15.6% (17/109) codes in common with the Elixhauser index (Appendix 1, Supplemental Digital Content 1, http://links.lww.com/MLR/C774). We observed a weak to moderate correlation between HFRS and both Charlson and Elixhauser (Spearman $R = 0.39$–0.42), and a moderate correlation between Charlson and Elixhauser (Spearman = 0.67).

The HFRS, Charlson, and Elixhauser indices were all associated with an increased risk of 30-day inpatient mortality and long LOS (Fig. 1). Table 2 presents their relationship with outcomes, either separately or combined. As illustrated in Figure 2, the best discrimination for predicting 30-day inpatient mortality was obtained by associating HFRS + adjustment + Charlson (Fig. 2, c-stat = 0.675), while HFRS + adjustment + Elixhauser performed the best for predicting long LOS (c-stat = 0.696). Although this last model came close, none of the c-statistics exceeded the limit of 0.70, which means that these models all had fair discrimination.

TABLE 1. Characteristics of Patients

Characteristic	N = 1,042,234
Male, N (%)	417,487 (40.1)
Age, mean (SD)	84.9 (5.8)
City of residence median income (K€), mean (SD)	20.6 (3.4)
Number of past hospital bed-days, mean (SD)	10.7 (18.2)
Number of past admissions (including ambulatory) in the 2 preceding years, mean (SD)	1.6 (2.2)
Length of index stay (nights), mean (SD)	8.6 (9.1)
Institution type, N (%)	
University hospital	202,632 (19.4)
Public	742,462 (71.2)
Private for profit	97,140 (9.3)
Medical accessibility, mean (SD)	4.1 (1.1)
Hospital Frailty Risk Score (HFRS), N (%)	
<5	472,816 (45.4)
5–15	386,894 (37.1)
>15	182,524 (17.5)
Charlson Comorbidity Index (CCI), N (%)	
0	318,482 (30.6)
1	304,393 (29.2)
2	209,676 (20.1)
≥ 3	209,683 (20.1)
Elixhauser Comorbidity Index (ECI), N (%)	
0–1	303,553 (29.1)
2–3	330,596 (31.7)
4–5	224,443 (21.5)
≥ 6	183,642 (17.6)

Using only data before the index admission significantly reduced the discriminative abilities of the HFRS for both outcomes, especially prolonged LOS (Fig. 2). Combining subscores of HFRS and comorbidity indices affected discrimination for both outcomes (Table 3), with increases in the c-statistics in comparison to HFRS + Charlson adjusted models (0.677 vs. 0.676 for mortality and 0.692 vs. 0.684 for extended LOS), and decreases in the c-statistics in comparison to HFRS + Elixhauser adjusted models (0.657 vs. 0.660 and 0.696 vs. 0.698, respectively). The consideration of interactions did not affect model discrimination (Appendix 3, Supplemental Digital Content 1, http://links.lww.com/MLR/C774). When considering scores and indices as continuous variables, the benefits in terms of discrimination were limited (Appendix 4, Supplemental Digital Content 1, http://links.lww.com/MLR/C774).

DISCUSSION

For older patients admitted to acute care, we found that the HFRS adds discriminative ability to the Charlson and Elixhauser comorbidity indices, especially for predicting long LOS. The combined model with the highest c-statistic was obtained when associating the HFRS with standard adjustment and Charlson for 30-day inpatient mortality and with Elixhauser for long LOS. Yet, both c-stat remained just below 0.70, indicating only fair discrimination. HFRS was more effective than the 2 comorbidity indices for discriminating long LOS, which may be expected in view of its development and validation process.[21] However, while the addition of HFRS to Elixhauser seems relevant for discriminating the risk of long LOS, the gain obtained from combining HFRS with the Charlson score was low for 30-day mortality, suggesting

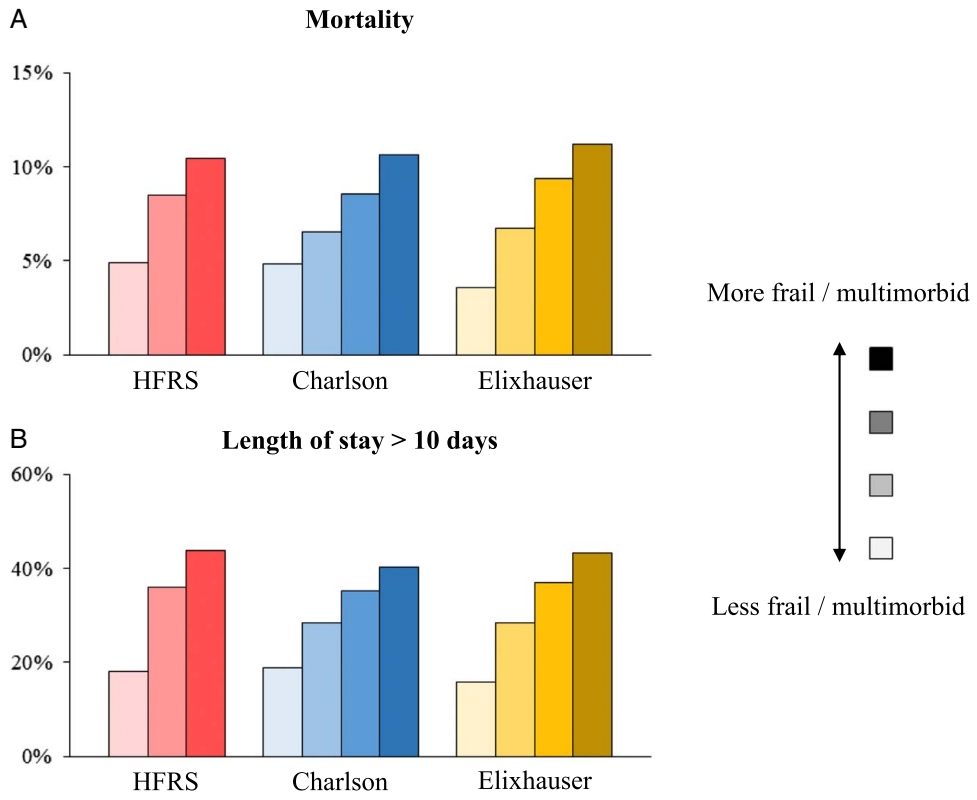

FIGURE 1. Share of each outcome per HFRS (< 5, 5–15, > 15), Charlson (0, 1, 2, ≥ 3), and Elixhauser (0–1, 2–3, 4–5, ≥ 6) category. (A) Mortality. (B) Length of stay > 30. HFRS indicates Hospital Frailty Risk Score.

that an adjusted Charlson model may be sufficient for this outcome.

Many approaches to measuring multimorbidity exist, consisting either in simply counting the number of co-occurring diseases, taking into consideration the burden on the patient's health or functional status of each condition, or creating risk prediction models.[8] The Charlson index and Elixhauser index are both examples of the latter approach. Most approaches usually focus on the most prevalent diseases or those with the most impact on outcomes.[7,8] The claims-version of Charlson's index using health records data from 6 countries (including France) has shown excellent predictive ability for 30-day mortality, reaching c-statistics up to 0.89.[32] This discrimination contrasts with that found in our study, with a c-statistic at best of 0.68. Quan et al[32] used data from the year 2004 with a look-back period of 1 year, but the main difference with our study was that <30% of patients were aged 65 years or older in their cohort. Similarly, in another larger study, Bannay et al[36] adapted the index on over 6 million French patients aged 18 years or older discharged from hospital and reached a c-statistic of 0.91 for predicting 1-year mortality. As our study focused on a population of older adults aged 75 years and over, this may have restricted the heterogeneity of the population and impacted discrimination.

A review of multimorbidity tools has confirmed that Charlson's comorbidity index is effective in predicting mortality (c-statistics ranging from 0.59 to 0.88 across studies).[8] However, this index was initially designed to predict 10-year mortality,[27] and is more effective in predicting longer-term mortality than inpatient mortality.[37] Similar observations can be made for Elixhauser index.[38]

In 2018, using 2 separate cohorts of over 300,000 individuals each in the years 2005 and 2011, Simard et al[31] obtained improved discrimination for predicting 30-day mortality by combining Elixhauser and Charlson indices (c-stat around 0.85), as compared with either independent measure. More recently, Pritchard and colleagues also obtained better model fit by including primary and secondary diagnoses over a look-back period of 1 year, and combining both measures, in spite of a certain overlap between these indices.

Nevertheless, it appears that all the previously cited models based on multimorbidity alone may not be sufficient to grasp the complexity of older patients. In a prospective study of older patients admitted to acute care, none of these indices (including Charlson's index) were superior to elements of comprehensive geriatric assessment, such as cognition of functional independence, in predicting 5-year mortality.[9] Although these multimorbidity indices are both associated with elements of comprehensive geriatric assessment such as frailty, dementia, polypharmacy, or malnutrition, key elements such as sensory deficits, functional independence or mobility problems, and nutritional deficiency may not be sufficiently captured.[39]

Previous reviews have shown that proxy scores based on electronic health records perform similarly to many vali-

TABLE 2. Relationship Between HFRS Frailty Score, Charlson, and Elixhauser Comorbidity Scores and Outcomes (n = 1,042,234)

	Basic adjustment + HFRS	Basic adjustment + Charlson	Basic adjustment + Elixhauser	Basic adjustment + HFRS + Charlson	Basic adjustment + HFRS + Elixhauser
30-d inpatient mortality					
HFRS					
Low	1.00	—	—	1.00	1.00
Intermediate	1.60 (1.57–1.62)	—	—	1.35 (1.32–1.37)	1.45 (1.42–1.48)
High	1.82 (1.78–1.86)	—	—	1.39 (1.36–1.42)	1.60 (1.56–1.63)
Charlson					
0	—	1.00	—	1.00	—
1	—	1.82 (1.77–1.86)	—	1.71 (1.67–1.75)	—
2	—	2.56 (2.50–2.62)	—	2.33 (2.27–2.39)	—
3+	—	3.09 (3.02–3.17)	—	2.75 (2.68–2.82)	—
Elixhauser					
0–1	—	—	1.00	—	1.00
2–3	—	—	1.31 (1.28–1.34)	—	1.19 (1.17–1.22)
4–5	—	—	1.68 (1.64–1.72)	—	1.46 (1.43–1.50)
6+	—	—	2.06 (2.00–2.11)	—	1.73 (1.68–1.77)
Length of stay > 10 d					
HFRS					
Low	1.00	—	—	1.00	1.00
Intermediate	2.66 (2.63–2.68)	—	—	2.34 (2.32–2.37)	2.19 (2.17–2.22)
High	4.05 (3.99–4.10)	—	—	3.27 (2.22–3.31)	3.12 (3.07–3.16)
Charlson					
0	—	1.00	—	1.00	—
1	—	1.69 (1.67–1.71)	—	1.43 (1.41–1.44)	—
2	—	2.36 (2.33–2.39)	—	1.82 (1.79–1.84)	—
3+	—	3.02 (2.97–3.06)	—	2.15 (2.12–2.18)	—
Elixhauser					
0–1	—	—	1.00	—	1.00
2–3	—	—	2.15 (2.13–2.18)	—	1.82 (1.80–1.84)
4–5	—	—	3.36 (3.32–3.41)	—	2.57 (2.53–2.60)
6+	—	—	5.02 (4.94–5.10)	—	3.59 (3.53–3.64)

Models were fitted with random effects to capture hospital variation and adjusted for age, gender, hospital bed-days, medical accessibility, city of residence median income (basic adjustment), and frailty/comorbidity scores. Results displayed are odds ratios with their 95% CIs.

HFRS indicates Hospital Frailty Risk Score.

dated clinical tools.[10,16] Although there is a strong case for preferring the frailty and multidomain assessment framework for risk stratification of older patients in acute care over multimorbidity,[40,41] these 2 approaches are possibly complementary.

Since its development and validation in 2018, the HFRS has been widely used and reliably validated in several countries.[22,24,25,42] Few studies have compared the discriminative abilities of HFRS with multimorbidity indices. In a Canadian study of patients with heart failure, only moderate agreement was found between Charlson's index and HFRS, although both were predictive of outcomes.[31] In another English study conducted on the national joint registry, Penfold et al[43] found that comorbidity indices or HFRS added little improvement beyond age, gender, and the ASA grade (American Society of Anesthesiologists) in predicting 90-day mortality or longer term in patients undergoing elective hip or knee replacement. Yet, Charlson's and Elixhauser indices (c-stat ranging from 0.78 to 0.81) slightly outperformed the HFRS (c-stat = 0.76–0.78).[43] This contrasts with a German retrospective study of 8250 patients who had undergone a total hip replacement, in which the HFRS (c-stat = 0.719) performed significantly better than Elixhauser (c-stat = 0.578) or Charlson (c-stat = 0.555) in predicting surgical complications, with similar results obtained for medical or other complications.[44]

In a recent cohort study conducted on health data of 107,188 patients admitted to intensive care units with a diagnosis of pneumonia, the HFRS and Charlson's index performed similarly for predicting inpatient deaths (both c-stat = 0.711) and were slightly better than the electronic frailty index,[17] c-stat = 0.677.[45] However, Charlson's index performed slightly better than the HFRS for predicting longer-term mortality (1-year mortality c-stat = 0.742 for Charlson; 0.728 for HFRS).[45] These results compare to previous studies and suggest that Charlson's index might be better at predicting longer-term outcomes.[37]

Another promising approach consists of creating electronic frailty indices using electronic health records.[17] Building on a previous American study,[46] Mak et al[19] have recently developed an electronic index aimed at hospitalized patients in Sweden, which displayed good discrimination for 30-day inpatient mortality (c-stat: 0.813; 95% CI: 0.769–0.857), and was also effective for predicting long LOS.

This study has several strengths. It was conducted on a large-scale and representative sample of all patients aged 75 years and over hospitalized is an emergency in all French hospitals over a whole year (2017). We performed a thorough exploratory study of the possible construction of all indices

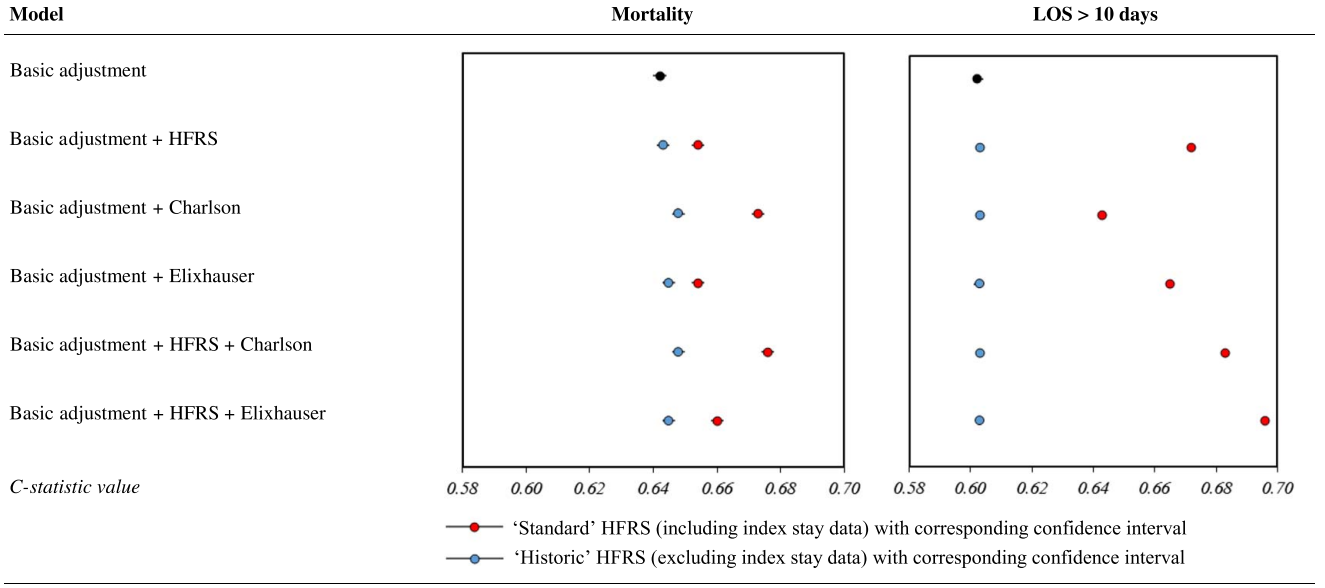

FIGURE 2. Model discrimination (c-statistic) for several models. Models were fitted with random effects to capture hospital variation. The basic adjustment model considered only the age, gender, hospital bed-days, medical accessibility, and city of residence median income. Then, frailty (HFRS) and comorbidity (Charlson or Elixhauser) scores were progressively added. Results displayed are c-statistics with their 95% CIs. HFRS indicates Hospital Frailty Risk Score.

and combinations. The HFRS was built according to the advised methodology,[21,47] and both comorbidity indices were constructed using comparable look-back periods, which are known to potentially affect results.[47,48]

This study has limitations. First, the use of health records data for creating risk scores is strongly dependent on the quality of coding, which inevitably impacts the accuracy of the measures. Second, as only inpatient mortality data was available to us, due to issues regarding authorization to access national mortality registries, the validity and generalizability of our results might be imperfect. According to French national statistics, in the year 2016, among the 594,000 people who died in France, 59% died in a health care establishment, 26% at home, 14% in a retirement home, and 1% on the public highway.[49] Similarly, the choice of a 10-day threshold for long LOS might be questioned. As the LOS is also a reflection of possibly divergent practices from one country to another, this may require an adjustment of this threshold for a given country, for more relevant interpretations.

The use of hospital administrative data to construct predictive scores is currently expanding due to its potential for automation and informing broadly about the needs of a population, at the hospital or territorial level.[14,46] This is particularly useful for health commissioners to rationalize

TABLE 3. C-statistics Per Outcome Using HFRS Subscores in Combination with Charlson or Elixhauser, and Either Unadjusted or Adjusted Models

	30-d inpatient mortality		Length of stay > 10 d	
Model	**Unadjusted**	**Adjusted**	**Unadjusted**	**Adjusted**
Basic adjustment	—	0.642 (0.640–0.644)	—	0.602 (0.601–0.604)
Basic adjustment + HFRS	0.617 (0.615–0.619)	0.654 (0.652–0.656)	0.669 (0.668–0.670)	0.672 (0.671–0.673)
Basic adjustment + Charlson	0.639 (0.637–0.641)	0.673 (0.671–0.675)	0.639 (0.638–0.641)	0.645 (0.644–0.646)
Basic adjustment + Elixhauser	0.610 (0.608–0.612)	0.654 (0.652–0.656)	0.661 (0.660–0.662)	0.668 (0.667–0.670)
Basic adjustment + HFRS + Charlson	0.649 (0.647–0.651)	0.676 (0.674–0.678)	0.679 (0.677–0.680)	0.684 (0.683–0.685)
Basic adjustment + HFRS + Elixhauser	0.628 (0.626–0.630)	0.660 (0.658–0.662)	**0.689 (0.688–0.690)**	**0.698 (0.697–0.699)**
Basic adjustment + HFRS_minC	0.612 (0.610–0.614)	0.651 (0.649–0.653)	0.669 (0.668–0.670)	0.672 (0.671–0.673)
Basic adjustment + HFRS_minE	0.602 (0.600–0.604)	0.647 (0.645–0.649)	0.658 (0.657–0.659)	0.660 (0.659–0.661)
Basic adjustment + HFRS_minC + Charlson	**0.650 (0.649–0.652)**	**0.677 (0.676–0.679)**	0.684 (0.683–0.685)	0.692 (0.691–0.693)
Basic adjustment + HFRS_minE + Elixhauser	0.621 (0.619–0.623)	0.657 (0.655–0.659)	0.686 (0.685–0.687)	0.696 (0.695–0.697)

Models were fitted with random effects to capture hospital variation.

Basic adjustment included the age, gender, hospital bed-days, medical accessibility, and the city of residence median income. Then, frailty (HFRS) and comorbidity (Charlson or Elixhauser) scores were progressively added. Finally, we also tried to use subscores of HFRS, and using the same 3 categories (< 5, 5–15, > 15): we constructed HFRS_minC (HFRS minus Charlson) by excluding F00, F01, F03, F05, G30, G31, G45, G81, I63, I67, I69, K26, N18, N19, and Z99, and HFRS_minE (HFRS minus Elixhauser) by excluding E86, E87, F10, F32, G20, G31, G40, G81, K26, N18, N19, R00, R47, R56, R63, Z50, and Z99. Index stay data were systematically considered in the score constructions.

Results displayed are c-statistics with their 95% CIs. Models with the highest C-statistics are highlighted in bold.

HFRS indicates Hospital Frailty Risk Score.

resources but can also contribute at the individual level to improve shared medical decisions.[14] Another key application of comorbidity indices is their use in epidemiological research to better characterize populations. Depending on the outcome of interest, our study shows that it may be useful to combine the HFRS with either Charlson or Elixhauser index, to improve the accuracy of the risk stratification in older patients.

The predictive power of these indices remains imperfect, but so are clinical risk stratification tools. In a previous meta-analysis on risk stratification instruments of older adults admitted to acute settings, Carpenter et al[10] found that none of the individual predictors of vulnerability or published instruments demonstrated sufficient prognostic accuracy to distinguish high-risk or low-risk subsets of patients. This task is made very complex by the multiplicity of risk factors for poor outcomes. Prognosis depends not only on multimorbidity and the degree of frailty, but also on the level of functional dependence, the acuity of the presenting condition, and socioeconomic factors.[10] In this context, the multidimensional frailty model therefore appears valid, and experts in geriatric emergency medicine advise the use of a frailty measure to stratify patients on arrival in the emergency department, with the aim of optimizing care and offering an individualized multidimensional approach to those most likely to benefit.[5] In this respect, alternative outcomes to mortality, more relevant to older people, such as time living at home or functional independence should be explored in future studies.[50,51]

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REFERENCES

1. Barnett K, Mercer SW, Norbury M, et al. Epidemiology of multimorbidity and implications for health care, research, and medical education: a cross-sectional study. *Lancet*. 2012;380:37–43.
2. Head A, Fleming K, Kypridemos C, et al. Inequalities in incident and prevalent multimorbidity in England, 2004–19: a population-based, descriptive study. *Lancet Healthy Longev* . 2021;2:e489–e497.
3. Blodgett JM, Rockwood K, Theou O. Changes in the severity and lethality of age-related health deficit accumulation in the USA between 1999 and 2018: a population-based cohort study. *Lancet Healthy Longev*. 2021;2:e96–e104.
4. Han L, Clegg A, Doran T, et al. The impact of frailty on healthcare resource use: a longitudinal analysis using the Clinical Practice Research Datalink in England. *Age Ageing*. 2019;48:665–671.
5. BGS: British Geriatrics Society. The Silver Book II—quality care for older people with urgent care needs. February 22, 2021. Accessed September 15, 2022. https://www.bgs.org.uk/resources/resource-series/silver-book-ii
6. Cesari M, Pérez-Zepeda MU, Marzetti E. Frailty and multimorbidity: different ways of thinking about geriatrics. *J Am Med Dir Assoc*. 2017;18:361–364.
7. Vetrano DL, Palmer K, Marengoni A, et al. Frailty and multimorbidity: a systematic review and meta-analysis. *J Gerontol A Biol Sci Med Sci*. 2019;74:659–666.
8. Diederichs C, Berger K, Bartels DB. The measurement of multiple chronic diseases—a systematic review on existing multimorbidity indices. *J Gerontol A Biol Sci Med Sci*. 2011;66:301–311.
9. Martínez-Velilla N, Cambra-Contin K, Ibáñez-Beroiz B. Comorbidity and prognostic indices do not improve the 5-year mortality prediction of components of comprehensive geriatric assessment in hospitalized older patients. *BMC Geriatr*. 2014;14:64.
10. Carpenter CR, Shelton E, Fowler S, et al. Risk factors and screening instruments to predict adverse outcomes for undifferentiated older emergency department patients: a systematic review and meta-analysis. *Acad Emerg Med*. 2015;22:1–21.
11. Soh CH, Hassan SWU, Sacre J, et al. Do morbidity measures predict the decline of activities of daily living and instrumental activities of daily living amongst older inpatients? A systematic review. *Int J Clin Pract*. 2021;75:e13838.
12. Clegg A, Young J, Iliffe S, et al. Frailty in elderly people. *Lancet*. 2013;381:752–762.
13. Hoogendijk EO, Afilalo J, Ensrud KE, et al. Frailty: implications for clinical practice and public health. *Lancet*. 2019;394:1365–1375.
14. Todd OM, Burton JK, Dodds RM, et al. New horizons in the use of routine data for ageing research. *Age Ageing*. 2020;49:716–722.
15. Soong JTY. Frailty measurement in routinely collected data: challenges and benefits. *Lancet Healthy Longev*. 2021;2:E117–E118.
16. Soong J, Poots AJ, Scott S, et al. Developing and validating a risk prediction model for acute care based on frailty syndromes. *BMJ Open*. 2015;5:e008457.
17. Clegg A, Bates C, Young J, et al. Development and validation of an electronic frailty index using routine primary care electronic health record data. *Age Ageing*. 2016;45:353–360.
18. Segal JB, Chang HY, Du Y, et al. Development of a claims-based frailty indicator anchored to a well-established frailty phenotype. *Med Care*. 2017;55:716–722.
19. Mak JKL, Hägg S, Eriksdotter M, et al. Development of an electronic frailty index for hospitalized older adults in Sweden. *J Gerontol Ser A*. 2022;77:2311–2319.
20. Subramaniam A, Ueno R, Tiruvoipati R, et al. Defining ICD-10 surrogate variables to estimate the modified frailty index: a Delphi-based approach. *BMC Geriatr*. 2022;22:422.
21. Gilbert T, Neuburger J, Kraindler J, et al. Development and validation of a Hospital Frailty Risk Score focusing on older people in acute care settings using electronic hospital records: an observational study. *Lancet*. 2018;391:1775–1782.
22. McAlister F, van Walraven C. External validation of the Hospital Frailty Risk Score and comparison with the Hospital-patient One-year Mortality Risk Score to predict outcomes in elderly hospitalised patients: a retrospective cohort study. *BMJ Qual Saf*. 2019;28:284–288.
23. Shebeshi DS, Dolja-Gore X, Byles J. Validation of hospital frailty risk score to predict hospital use in older people: evidence from the Australian Longitudinal Study on Women's Health. *Arch Gerontol Geriatr*. 2021;92:104282.
24. Eckart A, Hauser SI, Haubitz S, et al. Validation of the hospital frailty risk score in a tertiary care hospital in Switzerland: results of a prospective, observational study. *BMJ Open*. 2019;9:e026923.
25. Gilbert T, Cordier Q, Polazzi S, et al. External validation of the Hospital Frailty Risk Score in France. *Age Ageing*. 2022;51:afab126.
26. Hanlon P, Nicholl BI, Jani BD, et al. Frailty and pre-frailty in middle-aged and older adults and its association with multimorbidity and mortality: a prospective analysis of 493 737 UK Biobank participants. *Lancet Public Health*. 2018;3:e323–e332.
27. Charlson ME, Pompei P, Ales KL, et al. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. *J Chronic Dis*. 1987;40:373–383.
28. Quan H, Sundararajan V, Halfon P, et al. Coding algorithms for defining comorbidities in ICD-9-CM and ICD-10 administrative data. *Med Care*. 2005;43:1130–1139.
29. Elixhauser A, Steiner C, Harris DR, et al. Comorbidity measures for use with administrative data. *Med Care*. 1998;36:8–27.
30. Pritchard E, Fawcett N, Quan TP, et al. Combining Charlson and Elixhauser scores with varying lookback predicated mortality better than using individual scores. *J Clin Epidemiol févr*. 2021;130:32–41.
31. Simard M, Sirois C, Candas B. Validation of the combined Comorbidity Index of Charlson and Elixhauser to predict 30-day mortality across ICD-9 and ICD-10. *Med Care*. 2018;56:441–447.
32. Quan H, Li B, Couris CM, et al. Updating and validating the Charlson comorbidity index and score for risk adjustment in hospital discharge abstracts using data from 6 countries. *Am J Epidemiol*. 2011;173:676–682.
33. Deyo RA, Cherkin DC, Ciol MA. Adapting a clinical comorbidity index for use with ICD-9-CM administrative databases. *J Clin Epidemiol*. 1992;45:613–619.

34. Haviari S, Chollet F, Polazzi S, et al. Effect of data validation audit on hospital mortality ranking and pay for performance. *BMJ Qual Saf*. 2019;28:459–467.
35. Schober P, Boer C, Schwarte LA. Correlation coefficients: appropriate use and interpretation. *Anesth Analg*. 2018;126:1763–1768.
36. Bannay A, Chaignot C, Blotière PO, et al. The best use of the Charlson Comorbidity Index with electronic health care database to predict mortality. *Med Care*. 2016;54:188–194.
37. Soh CH, Ul Hassan SW, Sacre J, et al. Morbidity measures predicting mortality in inpatients: a systematic review. *J Am Med Dir Assoc*. 2020;21:462–468.e7.
38. Gutacker N, Bloor K, Cookson R. Comparing the performance of the Charlson/Deyo and Elixhauser comorbidity measures across five European countries and three conditions. *Eur J Public Health*. 2015;25(suppl 1):15–20.
39. Canaslan K, Ates Bulut E, Kocyigit SE, et al. Predictivity of the comorbidity indices for geriatric syndromes. *BMC Geriatr*. 2022;22:440.
40. Kaeppeli T, Rueegg M, Dreher-Hummel T, et al. Validation of the clinical frailty scale for prediction of thirty-day mortality in the emergency department. *Ann Emerg Med*. 2020;76:291–300.
41. Rueegg M, Nissen SK, Brabrand M, et al. The clinical frailty scale predicts 1-year mortality in emergency department patients aged 65 years and older. *Acad Emerg Med*. 2022;29:572–580.
42. Shimizu A, Maeda K, Fujishima I, et al. Hospital Frailty Risk Score predicts adverse events in older patients with vertebral compression fractures: analysis of data in a nationwide in-patient database in Japan. *Geriatr Gerontol Int*. 2022;22:233–239.
43. Penfold CM, Whitehouse MR, Blom AW, et al. A comparison of comorbidity measures for predicting mortality after elective hip and knee replacement: a cohort study of data from the National Joint Registry in England and Wales. *PLoS One*. 2021;16:e0255602.
44. Meyer M, Parik L, Greimel F, et al. Hospital frailty risk score outperforms current risk stratification models in primary total hip and knee arthroplasty. *J Arthroplasty*. 2021;36:1533–1542.
45. Szakmany T, Hollinghurst J, Pugh R, et al. Frailty assessed by administrative tools and mortality in patients with pneumonia admitted to the hospital and ICU: a population-based data-linkage study. In review. *Sci Rep*. 2021;11:13407.
46. Pajewski NM, Lenoir K, Wells BJ, et al. Frailty screening using the electronic health record within a medicare accountable care organization. *J Gerontol: Ser A*. 2019;74:1771–1777.
47. Street A, Maynou L, Gilbert T, et al. The use of linked routine data to optimise calculation of the Hospital Frailty Risk Score on the basis of previous hospital admissions: a retrospective observational cohort study. *Lancet Healthy Longev* . 2021;2:e154–e162.
48. Sharabiani MTA, Aylin P, Bottle A. Systematic review of comorbidity indices for administrative data. *Med Care*. 2012;50:1109–1118.
49. INSEE: Institut National de la Statistique des des Etudes Economiques. INSEE FOCUS N°95. 594 000 personnes décédées en France en 2016, pour un quart d'entre elles à leur domicile. October 12, 2017. Accessed June 12, 2023. https://www.insee.fr/fr/statistiques/3134763
50. Kellett J. Death is not the only healthcare outcome important to patients. *Eur J Intern Med*. 2016;32:e11–e12.
51. Hilmer S, Hubbard RE. Where next with frailty risk scores in hospital populations. *Age Ageing*. 2022;51:afab203.