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**Article (Published version)  
(Refereed)**

**Original citation:**

Gilbert, Thomas and Neuburger, Jenny and Kraindler, Joshua and Keeble, Eilis and Smith, Paul and Ariti, Cono and Arora, Sandeepa and Street, Andrew and Parker, Stuart and Roberts, Helen C. and Bardsley, Martin and Conroy, Simon (2018) *Development and validation of a Hospital Frailty Risk Score focusing on older people in acute care settings using electronic hospital records: an observational study*. [The Lancet](#). ISSN 0140-6736 (In Press)

DOI: [10.1016/S0140-6736\(18\)30668-8](https://doi.org/10.1016/S0140-6736(18)30668-8)

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Available in LSE Research Online: May 2018

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# Development and validation of a Hospital Frailty Risk Score focusing on older people in acute care settings using electronic hospital records: an observational study



Thomas Gilbert\*, Jenny Neuburger\*, Joshua Kraindler\*, Elisis Keeble, Paul Smith, Cono Ariti, Sandeepa Arora, Andrew Street, Stuart Parker, Helen C Roberts, Martin Bardsley, Simon Conroy



## Summary

**Background** Older people are increasing users of health care globally. We aimed to establish whether older people with characteristics of frailty and who are at risk of adverse health-care outcomes could be identified using routinely collected data.

**Methods** A three-step approach was used to develop and validate a Hospital Frailty Risk Score from International Statistical Classification of Diseases and Related Health Problems, Tenth Revision (ICD-10) diagnostic codes. First, we carried out a cluster analysis to identify a group of older people ( $\geq 75$  years) admitted to hospital who had high resource use and diagnoses associated with frailty. Second, we created a Hospital Frailty Risk Score based on ICD-10 codes that characterised this group. Third, in separate cohorts, we tested how well the score predicted adverse outcomes and whether it identified similar groups as other frailty tools.

**Findings** In the development cohort ( $n=22139$ ), older people with frailty diagnoses formed a distinct group and had higher non-elective hospital use (33.6 bed-days over 2 years compared with 23.0 bed-days for the group with the next highest number of bed-days). In the national validation cohort ( $n=1013590$ ), compared with the 429762 (42.4%) patients with the lowest risk scores, the 202718 (20.0%) patients with the highest Hospital Frailty Risk Scores had increased odds of 30-day mortality (odds ratio 1.71, 95% CI 1.68–1.75), long hospital stay (6.03, 5.92–6.10), and 30-day readmission (1.48, 1.46–1.50). The c statistics (ie, model discrimination) between individuals for these three outcomes were 0.60, 0.68, and 0.56, respectively. The Hospital Frailty Risk Score showed fair overlap with dichotomised Fried and Rockwood scales (kappa scores 0.22, 95% CI 0.15–0.30 and 0.30, 0.22–0.38, respectively) and moderate agreement with the Rockwood Frailty Index (Pearson's correlation coefficient 0.41, 95% CI 0.38–0.47).

**Interpretation** The Hospital Frailty Risk Score provides hospitals and health systems with a low-cost, systematic way to screen for frailty and identify a group of patients who are at greater risk of adverse outcomes and for whom a frailty-attuned approach might be useful.

**Funding** National Institute for Health Research.

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## Introduction

Older people (conventionally aged at least 65 years according to WHO) are major users of acute hospital care in developed countries,<sup>1,2</sup> and increasingly in the developing world.<sup>3</sup> In England, a fifth of hospital admissions in 2014–15 were among people aged 75 years and older, accounting for around 40% of all days spent in hospital.<sup>4</sup> For some older people, hospital admission is associated with an increased risk of harm over and above the presenting clinical condition.<sup>5</sup> Several attempts have been made to identify people at high risk of poor outcomes, many focusing on frailty.<sup>5,6</sup> Frailty describes a decline in function across several organ systems, linked to ageing, but progressing at different rates in different people; it is characterised by increased risk of poor outcomes in individuals exposed to an apparently innocuous stressor.<sup>7</sup>

Since frailty is potentially a determinant of the way care resources are used, the assessment of frailty should also inform processes of planning service provision and resource allocation, but there are major barriers to identification of frail older people. First, although many tools are available to measure frailty, commonly used measures show only moderate overlap in their identification of frailty<sup>8</sup> and there is substantial variability in which tool is chosen and when it is used.<sup>9</sup> Second, most tools are too complicated for use in acute care settings, and even shorter tools such as the Clinical Frailty Scale<sup>10</sup> and Identification of Seniors at Risk<sup>11</sup> tool require some form of manual assessment process, which can be time consuming and subject to inter-operator error. Finally, when frailty tools are used, they are applied for only a subset of patients, with most older people in hospital not having their frailty assessed at all.

Published Online  
April 26, 2018  
[http://dx.doi.org/10.1016/S0140-6736\(18\)30668-8](http://dx.doi.org/10.1016/S0140-6736(18)30668-8)

See Online/Comment  
[http://dx.doi.org/10.1016/S0140-6736\(18\)30907-3](http://dx.doi.org/10.1016/S0140-6736(18)30907-3)

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### Research in context

#### Evidence before this study

Frailty is associated with adverse clinical outcomes (eg, delirium and functional decline) in older people admitted to hospital. We searched for systematic reviews and meta-analyses describing acute hospital services in the Cochrane Database of Systematic Reviews, Database of Reviews of Effectiveness, MEDLINE, and Embase from 2005 to Feb 28, 2017. Search terms included “acute care”, (“frail elderly” OR “frail”), “geriatric assessment”, “health services for the aged”, “needs assessment”, and “risk assessment”. A systematic review showed that frailty or related risk scores focusing on older people can identify those at risk of adverse outcomes. Although most scales perform better than chance at predicting a range of poor outcomes, none has emerged as a globally recognised gold standard method for identifying risk of adverse events. Furthermore, frailty is not routinely captured in hospital coding systems, meaning frail older people remain anonymous at the system level (eg, to commissioners), in contrast to people with specific diseases such as stroke.

#### Added value of this study

The Hospital Frailty Risk Score developed and validated in this work performs at least as well as existing frailty or risk

stratification tools and better than many. It has the advantage of being derived from International Statistical Classification of Diseases and Related Health Problems, Tenth Revision (ICD-10) codes, so can be used wherever ICD-10 coding systems are in place. A key advantage is that the score can be implemented into hospital information systems, removing the inter-operator variability and implementation burden associated with manual scoring systems.

#### Implications of all the available evidence

There are clear potential benefits to routinely identifying older people at risk of adverse clinical or service outcomes, or both, in acute hospital settings, primarily the ability to tailor frailty-attuned interventions from the point of arrival and throughout the hospital stay. Additional benefits include service mapping, commissioning, and assessment focusing on older people with frailty. A globally accepted method of identifying frail older people in acute hospital settings can help highlight the magnitude of the issue, enable services to evolve to provide frailty-attuned care, and improve patient and service outcomes.

We aimed to establish whether a Hospital Frailty Risk Score could be developed using the International Statistical Classification of Diseases and Related Health Problems, Tenth Revision (ICD-10)<sup>12</sup> coding system, which is implemented in administrative hospital databases in many countries worldwide.

## Methods

### Study design

We used a three-step approach to develop and validate a Hospital Frailty Risk Score, based on ICD-10 codes. First, we undertook a cluster analysis to test whether a distinct group of older patients admitted to hospital with characteristics of frailty could be identified on the basis of their ICD-10 codes and resource use. Second, we created the Hospital Frailty Risk Score using ICD-10 codes that were over-represented in the group. Third, in two separate validation cohorts, we tested how well the Hospital Frailty Risk Score predicted adverse outcomes after an emergency admission, and whether it identified similar people as other clinical frailty tools.

We analysed the 2013–14 and 2014–15 Hospital Episode Statistics (HES) inpatient database, which contains information about all patients admitted to National Health Service (NHS) hospitals in England. HES data capture illnesses and related conditions, with each electronic record containing up to 20 diagnosis fields coded according to ICD-10.<sup>12</sup> The diagnostic codes are entered by professional coders using information gathered retrospectively from medical records. A unique anonymised identifier can be used to link several electronic records (including emergency department and

outpatient attendances) for the same patient, and to link records to Office for National Statistics mortality data.<sup>13</sup>

For the validation work, HES data were linked to a cohort of people who had been studied during an acute hospital admission in the East Midlands, UK, and who had been assessed for frailty using established scales. Records were linked by NHS Digital using deterministic linkage based on a hierarchy of patient identifiers (date of birth, postcode, sex, and NHS number); de-identified data were provided for the analysis.

Ethical approval was provided by Essex National Research Ethics Committee (East of England; reference 15/EE/024).

### Development cohort

We extracted a cohort of people aged 75 years and older who were discharged from hospital between April 1, 2013, and March 31, 2015. The cohort was restricted to elective, non-elective, and day case admissions to NHS hospitals, excluding mental health and community health providers. Since cluster analysis is a computationally intensive process, we further restricted our analysis to an 80% random sample of people living in Southampton, Leicester, or Nottingham, using the random selection function in SAS. These areas were chosen because they represent mixed urban and rural health and social care economies.

In cluster analyses, patients are grouped together based on their similarity to each other across several characteristics. Three sets of variables were used to create the clustering matrix: ICD-10 diagnoses, bed-days, and hospital costs. Diagnoses were based on the first

three characters of all ICD-10 codes used in any of the 20 diagnostic fields of the patient's records over a 2-year period. Rare diagnoses (fewer than 15 000 patients nationally) were excluded. Bed-days were calculated as the total number of days in hospital for the same period. Costs were calculated using 2014–15 health-care resource group national tariffs and 2013–14 reference costs data.<sup>14</sup>

To create a similarity score that could be used to group patients, we used Gower's method for combining binary (ICD-10 diagnoses) and continuous (bed-days and cost) variables.<sup>15</sup> This method involved range standardisation to convert the continuous variables to a scale from 0 to 1. Patients were then assigned to clusters using Ward's hierarchical clustering method.<sup>16</sup> This is an agglomerative (ie, bottom-up) process in which each patient starts in his or her own cluster, and pairs of clusters are merged step by step. The number of clusters was chosen pragmatically, to balance maximisation of the variance in similarity scores explained by the groups against production of the lowest number of clusters for clinically relevant interpretation.

To identify a cluster of patients with characteristics of frailty, we used a small set of ICD-10 codes identified a priori as being candidate markers of frailty (appendix). We also calculated the prevalence of coded frailty syndromes (cognitive impairment, functional dependence, falls and fractures, anxiety and depression, incontinence, pressure ulcers, and mobility problems) in each group, using a published model derived from ICD-10 codes.<sup>17</sup> We also compared the admission history, the Charlson comorbidity index (a method of estimating risk of mortality from comorbid disease at a specified timepoint in longitudinal studies),<sup>18</sup> and 2-year mortality in each group.

Risk stratification using a clustering method is computationally intensive and not easily replicable by individual hospitals, so we created an algorithm that could be more easily implemented, guided by the results of the cluster analysis. We derived a score based on ICD-10 codes that were at least twice as prevalent in the frail cluster as in the rest of the cohort. Points were awarded for each ICD-10 code that were proportional to how strongly they predicted membership of the cluster. Points were calculated using regression coefficients from a logistic regression model that included membership of the frail cluster as the binary dependent variable and the set of ICD-10 codes as binary predictor variables. Many of the ICD-10 codes were correlated with one another, so we included a penalty when fitting the model to shrink coefficients on individual predictor variables within correlated groups. We used a *c* statistic to assess how well this model discriminated between the frail cluster and the rest of the cohort. The resulting score is referred to as the Hospital Frailty Risk Score. Three categories, low risk, intermediate risk, and high risk, were created to aid interpretation, with cut-points selected pragmatically to create categories that discriminated most strongly

between individuals with different outcomes (see later). Further details are given in the appendix.

### Validation cohorts

In the first validation exercise, a national cohort was used to test how well the Hospital Frailty Risk Score predicted outcomes among people aged 75 years or older admitted to an acute hospital as an emergency between April 1, 2014, and March 31, 2015. We did a sensitivity analysis to ascertain whether including individuals also represented in the developmental cohort affected the results.

We fitted logistic regression models to estimate the associations of the Hospital Frailty Risk Score to three outcomes: 30-day mortality, long hospital stay (>10 days in hospital), and emergency readmission within 30 days of discharge (excluding patients who died in hospital). We estimated models with and without adjustment for the effects of patients' age, sex, socioeconomic status, admission history, and Charlson comorbidity index<sup>19</sup> as important predictors of these outcomes. Hospitals were included as random effects in the models to account for similarities in outcomes among patients treated in the same hospital compared with the whole population. Associations between the categories and each outcome are presented using odds ratios (ORs) with their 95% CIs. Model discrimination was summarised with a mean hospital-specific *c* statistic (appendix).

For the second validation exercise, we used a linked dataset on a local cohort of patients who had complete clinical frailty scale data and a linked HES record. These data were used to test agreement between frailty ratings based on our Hospital Frailty Risk Score and two prominent clinical measures of frailty: the Fried Phenotype and the Rockwood Frailty Index. The variables used to construct these two measures are described in the appendix. For the purpose of calculating

See Online for appendix

	Development cohort (n=22 139)	National validation cohort (n=1 013 590)	Local validation cohort (n=569)
Age (years)	82.5 (5.6)	84.1 (5.9)	79.9 (6.4)
Sex			
Female	12 796 (57.8%)	5 818 011 (57.4%)	317 (55.7%)
Male	9 343 (42.2%)	4 317 899 (42.6%)	252 (44.3%)
HES frailty risk score	8.9 (9.8)	9.0 (8.7)	5.6 (6.6)
HES frailty risk category			
Low risk (<5)	14 612 (66.0%)	4 297 662 (42.4%)	342 (60.1%)
Intermediate risk (5–15)	4 494 (20.3%)	3 811 110 (37.6%)	176 (30.9%)
High risk (>15)	3 033 (13.7%)	2 027 718 (20.0%)	51 (9.0%)
Charlson comorbidity index	2.8 (2.9)	2.9 (2.6)	1.9 (2.1)
Number of admissions over 2 years, including current admission			
1	10 029 (45.3%)	3 841 151 (37.9%)	161 (28.3%)
2	5 313 (24.0%)	2 229 989 (22.0%)	128 (22.5%)
≥3	6 797 (30.7%)	4 064 450 (40.1%)	280 (49.2%)

Data are mean (SD) or number (%). HES=Hospital Episode Statistics.

**Table 1: Characteristics of the three cohorts**

	Frailty	Elective cataracts	Chronic heart problems	Acute heart problems	Cancer and lung disease	Mixed diagnoses
Number of patients in cluster (% of development cohort)	4907 (22.2%)	3419 (15.4%)	1708 (7.7%)	1979 (8.9%)	3558 (16.1%)	6568 (29.7%)
Patient characteristics						
Mean age at start of period (years)	84.5	80.9	81.7	82.8	82.4	82.1
Number of women (%)	2964 (60.4%)	2010 (58.8%)	874 (51.2%)	980 (49.5%)	2021 (56.8%)	3947 (60.1%)
Variables used to form clusters						
Mean number of non-elective days*	33.6	1.4	6.0	23.0	16.8	6.1
Mean number of elective days*	0.8	0.3	0.7	1.2	0.9	0.9
Mean elective inpatient costs (£)*	583	923	1006	1159	1185	1018
Mean non-elective inpatient costs (£)*	8374	580	2350	6910	4885	2173
Variables used to identify clusters						
Number of people with predefined ICD-10 frailty marker (%)	4073 (83.0%)	274 (8.0%)	342 (20.0%)	831 (42.0%)	1459 (41.0%)	2102 (32.0%)
Number of people with at least one ICD-10 frailty syndrome (%)	4259 (86.8%)	397 (11.6%)	442 (25.9%)	1003 (50.7%)	1697 (47.7%)	2509 (38.2%)
Number of people who died during 2-year period (%)	2350 (47.9%)	263 (7.7%)	284 (16.6%)	750 (37.9%)	1637 (46.0%)	1018 (15.5%)
Mean Charlson comorbidity index	4.4	0.8	2.1	4.4	3.9	1.6
Mean total number of admissions	3.5	1.6	2.0	3.3	2.9	1.8

The names given to clusters are indicative, based on over-represented ICD-10 diagnoses in each cluster (table 3). ICD-10=International Statistical Classification of Diseases and Related Health Problems, Tenth Revision. \*Per patient.

**Table 2: Groups produced by cluster analysis in the development cohort**

agreement, patients were classified as either frail or non-frail using each scale. The Fried model is based on five items, and for this study frailty was defined as having three or more items present.<sup>20</sup> The Rockwood Frailty Index is based on a cumulative deficit of items, presented as a proportion of total items. For this study, a threshold of 0.25 was used to indicate frailty, because this has been proposed as a useful operational cut-off.<sup>21</sup> For our Hospital Frailty Risk Score, those in the intermediate-risk and high-risk categories were classified as frail. We assessed agreement using kappa coefficients with their 95% CIs. Additionally, Pearson's correlation coefficient was used to describe the association between the continuous versions of the Hospital Frailty Risk Score and the Rockwood Frailty Index. Analyses were done in SAS version 9.4 and R version 3.3.0.

### Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. TG, JN, JK, EK, and MB had full access to all the data in the study and all authors had final responsibility for the decision to submit for publication.

### Results

Among the 22139 patients included in the development cohort, the mean age was 82.5 years (SD 5.6) and 12796 (57.8%) were female (table 1). 10029 (45.3%) had one hospital admission. To characterise the different groups in this cohort, six clusters were selected. The

characteristics of people in each of the clusters are summarised in table 2. Table 3 lists the ICD-10 codes that were over-represented in each of these clusters.

One of the six clusters was identified as likely to represent frailty based on the high proportion (4073 [83.0%] of 4907) of people with at least one frailty marker from the predefined list of ICD-10 codes (appendix), compared with 29.1% (5008 of 17232) in the rest of the cohort. The proportion of people with at least one frailty syndrome<sup>17</sup> documented was 4259 (86.8%) of 4907 in the frailty cluster and 6048 (35.1%) of 17232 in the remaining five clusters. The frail cluster made up a fifth of the cohort (4907 of 22139), but were more likely to be admitted and have longer non-elective bed-days (table 2). 2350 (47.9%) of 4907 people in the frail cluster died over the 2 years, compared with 3952 (22.9%) of the remaining 17232 in the cohort (table 2).

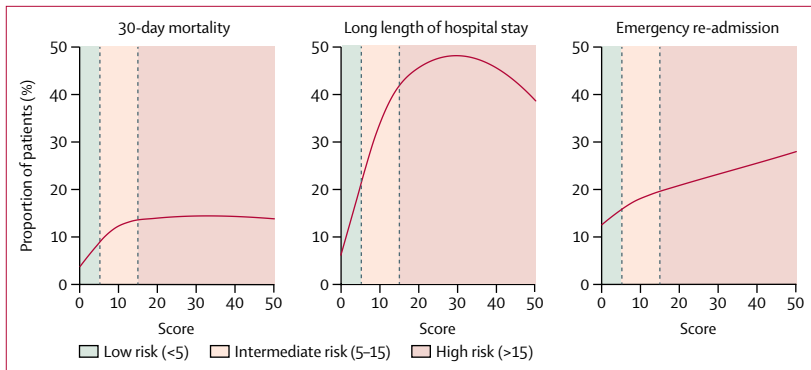
In the cluster analysis, 109 three-character ICD-10 diagnostic codes were at least twice as prevalent in the frail cluster than in other clusters in the development cohort (table 3 shows the top 36). The list included measures of acuity relevant to the hospital context, such as acute infections, hospital-acquired problems, and cerebrovascular disease, as well as recognised frailty syndromes such as falls, fractures, and cognitive impairment. The model including these ICD-10 codes as predictors discriminated strongly between patients in the frail versus other non-frail groups, with a c statistic of 0.94.

In the national validation cohort of 1013590 patients, 629440 (62.1%) had more than one previous admission

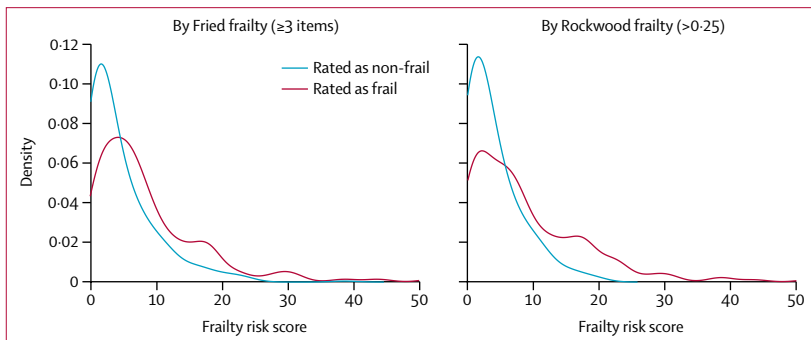


Category	Prevalence in group	Ratio to overall cohort	Category	Prevalence in group	Ratio to overall cohort		
<b>Frailty</b>			(Continued from previous column)				
F00	Dementia in Alzheimer's disease	11.5%	3.8	<b>Acute heart problems</b>			
F05	Delirium	18.8%	3.1	I08	Multiple valve disease	31.2%	5.3
G30	Alzheimer's disease	15.3%	3.1	Z82	Family history of certain disabilities and chronic diseases leading to disablement	9.4%	5.3
I69	Sequelae of cerebrovascular disease	7.0%	3.1	I24	Other acute ischaemic heart diseases	5.0%	5.2
Z75	Problems related to medical facilities and other health care	8.9%	3.1	I51	Complications and ill-defined descriptions of heart disease	46.4%	4.9
B96	Other bacterial agents as the cause of diseases classified to other chapters	18.7%	3.0	I21	Acute myocardial infarction	20.4%	4.8
S00	Superficial injury of head	11.6%	2.9	I34	Non-rheumatic mitral valve disorder	8.5%	3.9
G31	Other degenerative diseases of nervous system	8.5%	2.7	J90	Pleural effusion	26.3%	3.7
R41	Other symptoms and signs involving cognitive functions and awareness	24.9%	2.7	I27	Other pulmonary heart diseases	6.6%	3.6
L89	Decubitus ulcer	9.4%	2.7	I44	Atrioventricular and left bundle branch block	23.9%	3.6
R26	Abnormalities of gait and mobility	22.7%	2.7	I49	Other cardiac arrhythmias	6.7%	3.5
Y95	Nosocomial condition	9.1%	2.7	I50	Heart failure	49.8%	3.3
Z73	Problems related to life-management difficulty	5.1%	2.7	I35	Non-rheumatic aortic valve disorder	12.4%	3.2
R29	Other symptoms and signs involving the nervous and musculoskeletal systems	49.5%	2.7	Z95	Presence of cardiac and vascular implants and grafts	39.5%	3.2
N39	Other disorders of urinary system	45.5%	2.6	I20	Angina pectoris	35.6%	3.1
R45	Symptoms involving emotional state	5.3%	2.6	R06	Abnormalities in breathing	13.8%	3.0
E86	Volume depletion	18.2%	2.6	I71	Aortic aneurysm and dissection	7.3%	3.0
I67	Other cerebrovascular diseases	21.4%	2.6	I25	Chronic ischaemic heart disease	65.0%	2.9
F01	Vascular dementia	10.0%	2.6	I45	Other conduction disorders	10.4%	2.7
W19	Unspecified fall	29.8%	2.6	I73	Other peripheral vascular diseases	9.3%	2.7
W18	Other fall on same level	7.4%	2.5	R07	Pain in throat and chest	17.9%	2.7
R32	Urinary incontinence	9.4%	2.5	R00	Abnormalities of heart beat	15.0%	2.6
A41	Other septicaemia	10.5%	2.4	R60	Oedema	10.1%	2.5
S01	Wound of the head	8.3%	2.4	J98	Other respiratory disorders	10.8%	2.5
F03	Unspecified dementia	29.2%	2.4	Z92	Personal history of medical treatment	47.1%	2.3
M25	Other joint disorders	13.2%	2.3	R42	Dizziness and giddiness	6.8%	2.2
J69	Pneumonitis due to solids and liquids	5.1%	2.3	I48	Atrial fibrillation and flutter	51.3%	2.1
L97	Ulcer of lower limb, NEC	8.3%	2.3	E78	Disorders of lipoprotein metabolism	35.2%	2.1
K59	Other functional intestinal disorders	26.6%	2.3	R79	Other abnormal findings of blood chemistry	7.5%	2.0
N17	Acute renal failure	34.9%	2.2	<b>Cancer and lung disease</b>			
H54	Blindness and low vision	6.4%	2.2	C79	Secondary malignant neoplasm of other sites	9.3%	4.2
E87	Other disorders of fluid electrolyte and acid-base balance	25.5%	2.2	C78	Secondary malignant neoplasm of respiratory and digestive organs	10.5%	4.0
I95	Hypotension	17.2%	2.2	C34	Malignant neoplasm of bronchus and lung	5.7%	3.2
L03	Cellulitis	8.6%	2.2	Z51	Other medical care	26.9%	2.4
R33	Retention of urine	16.8%	2.2	J43	Emphysema	5.3%	2.2
S72	Fracture of femur	10.8%	2.2	J47	Bronchiectasis	5.2%	2.1
<b>Chronic heart problems</b>			J96	Respiratory failure	6.2%	2.0	
Z95	Presence of cardiac and vascular implants and grafts	31.9%	2.6	<b>Mixed diagnoses</b>			
I25	Chronic ischaemic heart disease	53.4%	2.4	NA	NA	NA	No individual code with ratio >2
I20	Angina pectoris	27.6%	2.4				
Z92	Personal history of medical treatment	47.8%	2.3	ICD-10=International Statistical Classification of Diseases and Related Health Problems, Tenth Revision. NA=not applicable. NEC=not elsewhere classified.			
I48	Atrial fibrillation and flutter	51.3%	2.1	<b>Table 3: Breakdown of ICD-10 codes at least twice as prevalent in each cluster compared with the overall cohort</b>			
<b>Elective cataracts</b>							
H25	Senile cataract	12.0%	3.2				
H26	Other cataract	24.6%	2.6				

(Table 3 continues in next column)



**Figure 1: Relation between Hospital Frailty Risk Scores and outcomes after emergency admission in the national validation cohort**  
 The vertical dashed lines show thresholds for categorising patients as low frailty risk (score <5), intermediate frailty risk (score 5–15), or high frailty risk (score >15).



**Figure 2: Distribution of Hospital Frailty Risk Scores among patients identified as frail and non-frail by the Fried and Rockwood scales**

over the 2 years before their index emergency admission, and 406 450 (40.1%) had three or more previous admissions (table 1). In common with the development cohort, over half (581 801 [57.4%]) were women and the mean age was 84.1 years (SD 5.9).

Patients had Hospital Frailty Risk Scores ranging from 0 to 99, but this was heavily skewed to the right: 429 762 (42.4%) were categorised as low risk using a cut-point score of less than 5, 381 110 (37.6%) as intermediate risk (5–15), and 202 718 (20.0%) as high risk (>15). The proportion of patients with poor outcomes increased with increasing values of the score, but the association with mortality flattened out above a score of 15 (figure 1). The association with having a long hospital stay reduced for the small group of patients with a score greater than 30.

Across the three categories of increasing frailty risk, the mean Charlson comorbidity index increased from 1.9 (SD 2.1) to 4.5 (2.7) and the proportion with three or more past admissions increased from 63 938 (14.7%) of 434 952 to 100 621 (49.2%) of 204 514 (appendix). The number of people with at least one frailty syndrome increased from 99 604 (22.9%) of 434 952 to 193 266 (94.5%) of 204 514, with the most striking gradient for cognitive impairment, increasing from 20 443 (4.7%) of 434 952 to 135 388 (66.2%) of 204 514.

The results of the analysis were not sensitive to the inclusion or exclusion of people included in the development cohort (appendix).

People with high frailty risk had a higher adjusted odds of 30-day mortality than those in the low-risk group (OR 1.71, 95% CI 1.68–1.75). They also had a higher adjusted odds of a long hospital stay (6.03, 5.92–6.10) and of emergency readmission within 30 days (1.48, 1.46–1.50).

The Hospital Frailty Risk Score discriminated weakly between individuals with different outcomes within hospitals; the c statistics were 0.60 for 30-day mortality, 0.68 for a long hospital stay, and 0.56 for 30-day readmission. The inclusion of patients' other characteristics (age, sex, deprivation, admission history, and comorbidity) improved discrimination to 0.69 for 30-day mortality, 0.73 for long hospital stay, and 0.61 for readmission.

In the second validation cohort, comprising 569 patients, the mean age was 79.9 years (SD 6.4), 317 (55.7%) were female, and 227 (39.9%) had a Hospital Frailty Risk Score above 5 (intermediate or high risk; table 1). The kappa score was 0.22 (95% CI 0.15–0.30) compared with a dichotomised version of Fried (>=3 items present) and 0.30 (0.22–0.38) compared with the Rockwood classification (using a cutoff of 0.25). There was a positive linear association between the Frailty Index and Hospital Frailty Risk Score (Pearson's correlation coefficient 0.41, 95% CI 0.38–0.47). The largest group for whom ratings differed were those with Hospital Frailty Risk Scores between 5 and 15 (figure 2), of whom only 40% were classified as frail by Rockwood.

## Discussion

From an initial cluster analysis, we identified a group that, when compared with other older people, had a higher incidence of ICD-10 codes judged a priori to be indicative of frailty, as well as higher hospital use and associated resource use. A Hospital Frailty Risk Score was derived from a broad set of ICD-10 codes that were over-represented in this cluster, including measures of acuity. In a national validation cohort of more than a million patients, those with higher frailty risk had higher risk of 30-day mortality, prolonged stay in hospital, and 30-day readmission. Although predictive at the group level, the ability of the score to discriminate between individuals with different outcomes was low. Using various thresholds to categorise patients as frail, the Hospital Frailty Risk Score showed fair to moderate overlap with ratings based on Fried and Rockwood frailty scales.

The advantage of using administrative hospital data to identify frailty risk is that it can be calculated using routine data for all patients in hospital and removes the need to apply a manual score. Although scores such as the Clinical Frailty Scale can be quick and simple to calculate,<sup>22</sup> they have inter-operator reliability issues and

impose a substantial implementation burden. A potential weakness of our score is that frailty among older people with few or no past admissions might be missed. Although these people are likely to be less frail than those with more or recent admissions,<sup>23</sup> there will be exceptions, particularly in care home settings or areas with successful admissions avoidance schemes. In the national cohort used to test the score, two-thirds of patients had been admitted in the previous 2 years.

The value of using administrative data has previously been shown in primary care, with the development and dissemination of the Electronic Frailty Index, which is based on Read codes used in most UK general practices.<sup>24</sup> The use of ICD-10 codes routinely entered in administrative databases provides hospitals with a systematic method to screen for frailty risk. In the present study, rather than relying exclusively on a predefined list of ICD-10 codes to identify frailty, we identified a wider set of codes using well established cluster analysis methods.<sup>25</sup> This approach allowed us to pick out the codes that are in routine use, rather than relying solely on opinion about which codes are most closely related to frailty.

Some diagnoses included in our score were associated with acute conditions such as aspiration pneumonia, delirium, and hospital-acquired or nosocomial infections. Arguably, these conditions could reflect frailty since these patients are likely to have swallowing problems, risk of dehydration, and be more vulnerable to hospital-acquired conditions and sepsis. However, our score can also identify other groups at risk of harm. A limitation of using ICD-10 is that the codes do not fully capture disease severity, and might also miss out important elements of frailty such as weakness, polypharmacy, and need for support in everyday living. Some of the ICD-10 Z codes reflect dependency or isolation, but these are typically only used when health-care delivery is adversely affected.

Another limitation of using ICD-10 is that variation in documentation and coding of diagnoses could contribute to measurement error.<sup>26</sup> For example, routine diagnosis and documentation of conditions such as delirium vary between physicians, departments, and hospitals. To examine this variation, we explored the effect of hospital coding depth (mean number of secondary ICD-10 diagnoses coded) as a measure of coding quality.<sup>27</sup> Among hospitals with better coding depth, a higher proportion of patients were classified as frail; nevertheless, the Hospital Frailty Risk Score was strongly predictive of poor outcomes even in hospitals with lower coding depths. In England, routinely collected data are sufficiently robust and accurate to be used in research or for health services planning,<sup>28</sup> and the score guards against the problem of coding depth by the use of three-character rather than four-character ICD-10 codes.<sup>28</sup> Nevertheless, coding accuracy will vary in other countries, and further validation work would need to be done in health-care systems wishing to test our approach.

Agreement between frailty ratings based on our Hospital Frailty Risk Score and other clinical frailty scales ranged between fair and moderate. This level of agreement is not uncommon with frailty scales, with, for example, kappa coefficients comparing Fried to Rockwood ranging from 0.3 to 0.5, depending on the measurement approach.<sup>29</sup> This range of scores shows the challenge in using any one frailty scale to diagnose an individual as frail.

Our score is comparable to tools specifically designed for risk stratification in emergency care settings, which also do not discriminate strongly, reflecting the fact that individual outcomes are inherently unpredictable in acute settings. For example, the Identification of Seniors at Risk tool<sup>11</sup> predicted 6-month mortality and readmission with c statistics ranging from 0.54 to 0.65. Our score performed similarly or slightly better than models including ICD-10 coded frailty syndromes as predictors of 30-day mortality and readmission.<sup>17</sup> The c statistics ranged from 0.57 to 0.66 for models including frailty syndromes, age, sex, and admission history.

The appendix provides the ICD-10 codes and methods to derive the score and risk categories, which can be implemented by hospitals and public health teams to facilitate routine identification of frail cohorts who are at risk of poor clinical or service outcomes, or both, in acute hospital settings. In a hospital admitting 1000 older people per month, 200 would be classified as high risk and a further 400 as intermediate risk, among whom mortality would be expected to be double that of other older patients. Identifying this group of patients would enable targeted screening for frailty syndromes and the delivery of frailty-attuned approaches to care. Examples include the Comprehensive Geriatric Assessment,<sup>30</sup> prevention of delirium<sup>31</sup> and functional deterioration,<sup>32</sup> and identification of end-of-life care needs<sup>33</sup> on a hospital-wide basis.<sup>34</sup>

Further research could examine how well the frailty risk score predicts outcomes other than mortality, the long-term relation with interventions, health and service utilisation outcomes, and the relation with primary care frailty scores, such as the electronic Frailty Index.<sup>24</sup> Additional studies might improve the accuracy of the score by examining the role of additional variables, such as physiological parameters of disease severity.<sup>35</sup> Additional work should explore the effect of the score on clinical decision making, in particular that it does not have the perverse effect of increasing therapeutic nihilism.<sup>36</sup>

#### Contributors

TG, JN, PS, CA, and MB designed the study; acquired, analysed, and interpreted data; and wrote and revised the manuscript. EK and JK acquired, analysed, and interpreted data; and wrote and revised the manuscript. SA interpreted data and wrote and revised the manuscript. AS, SP, HCR, and SC designed the study, interpreted data, and wrote and revised the manuscript.

#### Declaration of interests

We declare no competing interests.



**Acknowledgments**

This study was funded by the National Institute for Health Research (NIHR; HSDR 12/5003/02). The views expressed are those of the authors and not necessarily those of the NHS, the NIHR, or the Department of Health. We are grateful for the support of Theo Georghiou, Chris Sherlaw-Johnson, Miranda Davies, and Robert Atherton at the Nuffield Trust, and Kay Phelps, Emma Regen, and Janet Hood at the University of Leicester.

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