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The Dr Foster Global Frailty Score: an international risk prediction model for hospitalised older persons derived from administrative datasets

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Keywords:	Frailty, Secondary Care, Measure, Administrative, Risk Prediction

Dear Editor

We are pleased to submit this observational study developing and validating an international score for the measurement of frailty that was derived from routinely collected administrative data

This is the first frailty score derived from an international dataset from 34 hospitals from nine countries across Europe, Australia, the UK and USA, and has validation in large English national administrative data for important outcomes: in-hospital mortality, 30 day non-elective readmission and long length of hospital stay.

Important implications of this research include international case-mix adjustment and clinical risk stratification of older persons at population level

This is a follow up study from previous work we have published at the BMJ Open:

1. Soong J, Poots A, Scott S, Donald K, Bell D. Developing and validating a risk prediction model for acute care based on frailty syndromes. BMJ Open. 2015;5(10):e008457.
2. Soong J, Poots AJ, Scott S, Donald K, Woodcock T, Lovett D, et al. Quantifying the prevalence of frailty in English hospitals. BMJ Open. 2015;5(10):e008456.

We thank you for your kind consideration

Dr John Tshon Yit Soong

Title: The Dr Foster Global Frailty Score: an international risk prediction model for hospitalised older persons derived from administrative datasets

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Structured abstract 300 words. (300 words)

Objectives. This study aimed to examine the prevalence of frailty coding within the Dr Foster Global Comparators (GC) international database. We then aimed to develop and validate a risk prediction model, based on frailty syndromes, for key outcomes using the GC dataset.

Design. A retrospective cohort analysis of data from patients over 75 years of age from the GC international administrative data. A risk prediction model was developed from the initial analysis based on seven frailty syndrome groups and their relationship to outcome metrics. A weighting was then created for each syndrome group and summated to create the Dr Foster Global Frailty Score. Performance of the score for predictive capacity was compared with an established prognostic comorbidity model (Elixhauser) and tested on another administrative database Hospital Episode Statistics (2011-2015), for external validation.

Setting. 34 hospitals from nine countries across Europe, Australia, the UK and USA.

Results. Of 6.7 million patient records in the GC database, 1.4 M (20%) were from patients aged 75 years or more. There was marked variation in coding of frailty syndromes between countries and hospitals. Frailty syndromes were coded in 2-24% of patient spells. Falls and fractures was the most common syndrome coded (24%). The Dr Foster Global Frailty Score was significantly associated with in-hospital mortality, 30-day non-elective readmission and long length of hospital stay. The score had significant predictive capacity beyond that of other known predictors of poor outcome in older persons, such as co-morbidity and chronological age. The score's predictive capacity was higher in the elective group compared with non-elective, and may reflect improved performance in lower acuity states.

Conclusions: Frailty Syndromes can be coded in international secondary care administrative datasets. The Dr Foster Global Frailty Score significantly predicts key outcomes. This methodology may be feasibly utilised for case-mix adjustment for older persons internationally.

Article summary – strengths and limitations of this study

- This study is a large multicentre international study across Europe, Australia and the United States utilising a routinely collected administrative data with the aim of providing a simple model for case-mix adjustment for older persons in secondary care.
- The dataset used represent whole populations, and there was little missing data.
- Robust statistical methods were used and the Dr Foster Global Frailty Score was validated on an external dataset (Hospital Episode Statistics)
- Our model's predictive capacity is comparable with other recent single country studies
- The variability in frequency of coding of frailty syndromes across countries may limit reliability and generalisability.

Introduction

Increased population ageing stems from a range of diverse factors, including lower childhood and adult mortality, improved fertility, migration, relative world peace and improved health and social care(1). For many, this phenomenon is associated with good health and quality of life(2). For others, there is increased co-morbidity(3), functional decline(4) and poorer quality of life. Differences in the health and function of individuals as they grow older is not readily explained by chronological age(5). Frailty is common and increasingly prevalent with advancing age and often defined as a decrease in physiological reserve over a life-course. Using this pathophysiological model of frailty several underlying processes have been described, including chronic inflammation(6, 7), sarcopaenia(8), anaemia(9) and coagulopathy, steroid hormone dysregulation(10, 11), low vitamin D levels, malnutrition(12, 13) and insulin resistance(14, 15) underpin frailty. These deficits can accumulate over the course of life-time exposure to environmental stressors. Frailty manifests as a combination of the pathophysiological consequence of inbuilt senescence and the accumulation of defects throughout a life-course. Frailty ultimately results in recognisable clinical manifestations such as recurrent falls and delirium and is associated with increased mortality, disability and high resource utilisation(16). Conceptually and operationally, frailty appears to be related to, but distinct from, disability, co-morbidity and chronological age(17). The importance of contributing environmental factors and the psycho-social impact of frailty are increasingly being recognised(18) as important.

Assessing frailty in the hospital setting is challenging. Many frailty assessment scores tested have poor reliability, require large amounts of data, or specialised equipment and have poor predictive performance(19). Given these limitations, there is increasing interest in utilising routinely collected administrative data for risk prediction modelling for those at risk of frailty, particularly older persons. Risk prediction models estimate the likelihood of developing a specific outcome, or having a specific condition. These models can be utilised for the purposes of case-mix adjustment or risk-stratification. Case-mix risk adjustment allows for more accurate comparison of organisational performance by reducing confounding bias. For example, when considering mortality as an outcome measure for organisations, patient-specific factors such as illness severity influence outcome, and must be taken into account. Risk stratification allows for possible segmentation of a population into different levels of risk for developing a specific outcome. This segmentation can then be used to health system planning or inform targeting of resources.

In older persons, risk prediction models often utilise chronological age(20), co-morbidity(21) and functional dependence(22) as patient-specific factors for risk prediction. In the context of long-term care (e.g. nursing homes), risk prediction models often utilise functional dependence as a patient factor, to aid appropriate health resource utilisation and costing (23-25). A recent English study in the primary care setting derived an electronic frailty index from patient records with predictive validity for nursing home admission, hospitalisation and mortality (26). In secondary care, risk prediction models for older persons have utilised measures of demographics, and co-morbidity in the form of diagnostic (27-30) and procedural codes(31, 32), as well as prescription data(29, 33). Frailty syndromes are recognised as clinical manifestations of frailty(34). These common presentations in older persons include recurrent falls, cognitive impairment, incontinence and pressure ulcers, are associated with poor outcome. Recent studies have explored the coding of frailty syndromes within secondary care administrative datasets in the United Kingdom, and its association with in-hospital mortality, non-elective readmission and functional decline.(35, 36)

In this study, we explored the prevalence of coded frailty syndromes within an international secondary care dataset to develop and validate a risk prediction model based on frailty syndromes for the outcomes of mortality, non-elective readmission and long length of stay. We sought to compare the performance of this model with an established prognostic co-morbidity model for the above outcomes.

Methods

Data Sources

The Global Comparators programme at Dr Foster® was an international hospital collaborative which ran from 2011-2017, focused on pooling and benchmarking data, knowledge-sharing networks and health services research to better understand variations in outcomes and disseminate international best practice. The hospitals within the collaboration contributed administrative data to be pooled within the Global Comparators dataset, using established data cleaning processes(37). This provided a rich patient-level dataset containing demographics, diagnostic codes, procedure codes and outcomes, collected primarily for administrative purposes, such as operational needs and costing. To develop and test Dr Foster Global Frailty Score, Global Comparators data were extracted from 34 hospitals in nine countries: Australia, Belgium, Denmark, Finland, Italy, Netherlands, Norway, United Kingdom and United States.

Hospital Episode Statistics (HES) is an English national administrative dataset, housed within the safe haven of NHS Digital, and contains administrative data from English hospital trusts, which are cleaned and securely stored. This dataset was used to validate the Dr Foster Global Frailty Score. We included the 138 English acute non-specialist hospital trusts, excluding hyper-specialist hospitals (e.g. single pathology quaternary referral units) and mental health units, which have different case-mix.

Study Population

Patient records were included in the analysis if they fulfilled the criteria of patient age ≥75 years and required an elective or non-elective hospital admission of 24 hours or more. Patient spells were excluded if the age, sex or length of stay was recorded as missing or invalid, or the admission was planned and the patient discharged home on the same day, or the admission was unplanned but no procedure was undertaken and the patient went home after recorded length of stay less than 2 days. This was to exclude records with inadequate quality data, and patients admitted into observations units or day-case attendances. Overall, 0.17% of data were missing within the derivation dataset.

Coding frailty

Each patient record corresponded to a spell covering a patient's total length of stay at a hospital. Within HES, these were aggregated into 'superspells' (admissions), which encompass the full length of stay for the patient across all hospital trusts before their final discharge. Seven groups of frailty syndromes were chosen to represent the common domains used in comprehensive geriatric assessment: Dementia and Delirium, Mobility Problems, Falls and Fractures, Pressure Ulcers and Weight Loss, Incontinence, Dependence and Care, as well as Anxiety and Depression were coded within International Statistical Classification of Diseases, Injuries and Causes of Death (ICD) diagnostic coding groups, and within all available diagnostic fields. As the Global Comparators dataset comprised hospitals which utilised different revisions of ICD (revision 9 and 10), equivalent diagnostic codes for both versions were compiled. These diagnostic coding groups were modified from previously published work on English national administrative data(35). Appendix 1 displays the full list of ICD-9 and ICD-10 diagnostic codes utilised to code for the seven frailty syndrome groups. Trends by calendar year and month, country and frailty syndrome group were plotted to investigate frequency of coding for the years 2010-2014. Based on this analysis, years 2012-2013 were selected as having stable coding for multivariable risk prediction modelling within the derivation dataset.

Table 1: Predictors inputs for frailty risk prediction model (independent predictors)

Name	Time span	Description	Comments
Age	Current spell	Age on admission	
Gender	Current spell	Gender on admission	
Country	Current Spell	Country from which hospital contributed data	Nominal; Countries were: Australia Belgium Denmark Finland Italy Netherlands Norway United Kingdom United States
Dementia & Delirium	12-month historical binary indicator	A binary flag indicating whether a relevant diagnosis has been received during any inpatient spell in the past 12 months	Final Dr Foster Global Frailty Score is weighted (see risk stratification models section for further details)
Mobility Problems			
Falls & Fractures			
Pressure Ulcers & Weight Loss			
Dependence and Care			
Anxiety & Depression			
Co-morbidity (Elixhauser)	12-month historical score	A weighted score (see risk stratification	Integer

		models section for further details)	
Number of previous admissions	12-month historical count	The number of emergency admission spells in the previous 12 months, excluding the current spell	Integer

Table 2: Predictor outputs for frailty risk prediction model (dependent variables)

Name	**Time span**	**Description**	**Comments**
In-hospital mortality	Current spell	Indicates if the discharge method was death	
30-day non-elective readmission	30 days from discharge	Indicates if the patient had an emergency admission with admission date between 1 and 30 days following the discharge date of the index admission	Spells that ended in death are excluded from the analysis
Long length of stay	Current spell	Upper quartile length of hospital stay for country	

Risk Models

Within the Global Comparators dataset, 30 models were created. The characteristics of predictor and outcome variables included within the models are described in Tables 1 and 2. Elective and non-elective hospital admission populations were modelled separately. A two-step process for each outcome was utilised to model the frailty and comorbidity scores. First, binary logistic regression was utilised to ascertain odds ratios (ORs) for each frailty syndrome group and each outcome, within the population subgroups separately (elective and non-elective). The natural log of OR (*ln* OR) was used to create weights for each frailty syndrome group, using the smallest *ln* OR as reference (weighted 1.0). Secondly, the summation of the weights for each frailty syndrome group was utilised to create a frailty score. The patient-level frailty score was then included within a multivariable logistic regression model, adjusted for age, gender and country, for each outcome. Figure 1 illustrates an example of this two-step process for the outcome of upper quartile length of stay.

The Elixhauser co-morbidity score was calculated for each outcome using previously described methods(38). To provide comparison, the Elixhauser co-morbidity score was then included within a multivariable logistic regression model, adjusting for age, gender and country, for each outcome. Finally, both the Elixhauser co-morbidity and Dr Foster Global Frailty Score were then included within a multivariable logistic regression model, adjusted for age, gender and country, for each outcome. The predicted probabilities from these regression models were utilised to calculate Area under the Receiver Operator Characteristic Curves (AUC) as a measure of predictive capacity for each outcome. This two-step process was repeated for the Dr Foster Global Frailty Score on HES years 2011-2015 for external validation.

Performance metrics

Multicollinearity between predictor variables was investigated by variance inflation factor (VIF), where VIF scores of over three were taken to denote unacceptable collinearity. The Hosmer-Lemeshow statistic was calculated for each model to ascertain model calibration. The Wald statistic was calculated to explore the explanatory power of the Dr Foster Global Frailty Score, Elixhauser co-morbidity Score, age, country and gender for each of the three outcomes. Statistical analysis was undertaken using the R Statistical Package.

Results

Descriptive statistics

Of the 6,739,790 spells within the Global Comparators Database from 2010-2014, 1,366,187 (20%) involved patients aged ≥ 75 years. There was variation in frequency of coding of frailty syndromes across the countries. The four countries with most volume of coded frailty syndromes were Australia, Belgium, the United Kingdom and the United States. Figure 2a & 2b describes the percentage of spells of patients ≥ 75 years to total volume by country and year within the database, and the frequency of coding for frailty syndromes by country for the year 2013.

Coded Frailty Syndromes

Frailty syndromes were coded in 2-24% of patient spells among patients aged ≥ 75 years from 2010-2014 within the Global Comparators database: Falls and Fractures N=326,528 (24%); Dementia and Delirium N=215,629 (16%); Anxiety and Depression N=87,732 (6%); Pressure Ulcers and Weight Loss N=66,208 (5%); Incontinence N=50,277 (4%); Mobility Problems N=39,479 (3%); and Dependence and Care N=28,294 (2%). At least one frailty syndrome was present in 538,766 (39%) of spells.

Derivation Cohort

Of the 294,998 patient spells from 2012-2013 for those aged ≥ 75 years used in the predictive models within the derivation cohort from the Global Comparators Dataset, 221 441 (75%) were non-elective admissions and 158 595 were female (54%). Patient spells that ended with inpatient mortality (42,354, 14%) of were excluded from the predictive models exploring non-elective readmission.

Dr Foster Global Frailty Score

Negative scores were set to 0 and positive scores were not capped. The Dr Foster Global Frailty Score varied based on outcome and population (elective and non-elective), and remained significant after multivariable adjustment. Table 3 summarises the ORs of the Dr Foster Global Frailty Score and Elixhauser Co-morbidity Score after multivariable adjustment for age, gender and country for the outcomes of in-hospital mortality, 30-day non-elective readmission and upper quartile length of stay (for country), by elective and non-elective population groups. Appendix 2 displays full multivariable adjustment of the Dr Foster Global Frailty Score.

Table 3: Odds ratios for Elixhauser and Dr Foster Global Frailty Score after multivariable adjustment for age, gender and country

	Outcome	Score range	Population	Odds Ratio	Lower CI	Upper CI	P-value
Dr Foster Global Frailty Score	In-hospital mortality	0-11	Elective	1.277	1.247	1.308	<0.001
		0-13	Non-elective	1.109	1.103	1.116	<0.001
	30-day non-elective readmission	0-6	Elective	1.106	1.060	1.154	<0.001
		0-4	Non-elective	1.056	1.031	1.082	<0.001
	Upper Quartile Length of Stay (for country)	0-16	Elective	1.365	1.347	1.382	<0.001
		0-17	Non-elective	1.199	1.194	1.205	<0.001
Elixhauser co-morbidity score	In-hospital mortality		Elective	1.309	1.290	1.329	<0.001
			Non-elective	1.130	1.126	1.133	<0.001
	30-day non-elective readmission		Elective	1.144	1.130	1.158	<0.001
			Non-elective	1.045	1.042	1.048	<0.001
	Upper quartile length of stay (for country)		Elective	1.101	1.097	1.105	<0.001
			Non-elective	1.069	1.068	1.071	<0.001

When both the Dr Foster Global Frailty Score and Elixhauser co-morbidity Score were included in multivariable risk adjustment models for age, gender and country, the Dr Foster Global Frailty Score remained significant for the outcomes of in-hospital mortality and upper quartile length of stay, but not for 30-day non-elective readmission (Table 4).

Table 4: Odds ratios for Elixhauser and Dr Foster Global Frailty Score after multivariable adjustment for age, gender and country with both scores in model

Outcome	Population	Score	Odds Ratio	Lower CI	Upper CI	P-value
In-hospital mortality	Elective	Elixhauser	1.283	1.263	1.304	<0.001
		Frailty	1.114	1.085	1.144	<0.001
	Non-elective	Elixhauser	1.123	1.119	1.126	<0.001
		Frailty	1.058	1.052	1.065	<0.001
30-day non-elective readmission	Elective	Admission History*	1.273	1.234	1.314	<0.001
		Elixhauser	1.142	1.128	1.157	<0.001
		Frailty	1.032	0.988	1.077	0.160
	Non-elective	Admission History*	1.240	1.228	1.252	<0.001
		Elixhauser	1.045	1.042	1.048	<0.001
		Frailty	1.024	1.000	1.049	0.052
Upper quartile length of stay	Elective	Elixhauser	1.081	1.077	1.085	<0.001
		Frailty	1.243	1.227	1.260	<0.001
	Non-elective	Elixhauser	1.055	1.053	1.056	<0.001
		Frailty	1.137	1.131	1.142	<0.001

*Admission history included in multivariable model exploring 30-day non-elective readmission

The predictive capacity of the Dr Foster Global Frailty Score and Elixhauser co-morbidity score are compared in Table 5. When the Dr Foster Global Frailty Score and Elixhauser co-morbidity score are both included in a multivariable model adjusted for age, gender and country, the predictive capacity is moderate to good. The predictive capacity of the Elixhauser co-morbidity score generally exceeds that of the Dr Foster Global Frailty Score for all three outcomes.

Table 5: Area under the Receiver Operator Statistic Curve for outcomes by Elixhauser score, Dr Foster Global Frailty Score and population within Global Comparators dataset

Global Comparators Dataset	Elixhauser		Dr Foster Global Frailty Score		Elixhauser and Dr Foster Global Frailty Score	
Outcome/AUC	Elective	Non-elective	Elective	Non-elective	Elective	Non-elective
In-hospital mortality	0.80	0.69	0.70	0.62	0.81	0.69
30-day non-elective readmission*	0.67	0.64	0.64	0.63	0.67	0.64
Upper quartile length of stay	0.72	0.63	0.69	0.61	0.73	0.65

*Admission history included in multivariable model exploring 30-day non-elective readmission

The Wald statistic for independent variables included in final models by population and outcome are displayed in Table 6. Overall, the explanatory power of the Elixhauser co-morbidity score exceeds the Dr Foster Global Frailty Score for all three outcomes.

Table 6: Wald Statistic for independent variables of final models by outcome and population

	Upper quartile length of stay		30-day non-elective readmission		In-hospital mortality	
	Elective	Non-elective	Elective	Non-elective	Elective	Non-elective
Age	31.1	31.4	0.0	0.4	46.4	747.2
Sex	18.7	0.2	6.9	77.6	9.5	85.2
Country	162.0	244.2	31.1	102.1	12.8	137.8
Admission History	-	-	225.9	1888.4	-	-
Dr Foster Global Frailty Score	1020.7	2579.9	2.0	3.8	62.7	318.2
Elixhauser Score	1727.5	4075.1	420.4	848.4	973.9	4842.1

Performance metrics

All our models displayed significance at $p<0.05$ for the Hosmer-Lemeshow tests for goodness-of-fit test. These findings have been similarly described by others who have produced models on large data sets as the test is recognised to detect unimportant differences(38, 39). None of the predictor variables demonstrated unacceptable collinearity(40).

Validation Cohort

Of the 7,195,950 patient spells from 2011-2015 used in the predictive models within the validation cohort from English national Hospital Episode Statistics data, 6,128,811 (85%) were non-elective admissions, and 564,182 (7.8%) patient spells ending with in-hospital mortality were excluded from predictive models exploring non-elective readmission.

The Dr Foster Global Frailty Score remained significant after multivariable adjustment within the validation dataset. However, the predictive capacity and ORs were generally lower across all three outcomes compared to the derivation cohort. Table 7 summarises the ORs and AUC of the Dr Foster Global Frailty Score after multivariable adjustment for age, gender and calendar year for the outcomes of in-hospital mortality, 30-day non-elective readmission and upper quartile length of stay (for country), by elective and non-elective population groups. Appendix 3 displays full multivariable adjustment of the Dr Foster Global Frailty Score within the validation dataset.

Table 7: Odds ratios and for Area under the Receiver Operator Statistic Curve (AUC) for Global Frailty Score following multivariable adjustment for age, gender, calendar year by population subgroup and outcome

Outcome	Population	AUC	Odds Ratio	Lower CI	Upper CI	P-value
In-hospital mortality	Elective	0.649	1.173	1.171	1.174	<0.001
	Non-elective	0.655	1.108	1.107	1.109	<0.001
30-day non-elective readmission	Elective	0.630	1.045	1.044	1.047	<0.001
	Non-elective	0.630	1.030	1.030	1.031	<0.001
Upper Quartile Length of Stay (for country)	Elective	0.676	1.193	1.192	1.193	<0.001
	Non-elective	0.677	1.055	1.055	1.055	<0.001

*Admission history included in multivariable model exploring 30-day non-elective readmission

Discussion

Our study found that frailty syndromes are feasibly coded within a large (N≈1.3m) international dataset of hospitalised older persons (aged over 75 years) utilising readily available administrative data. This is consistent with a previous study using English administrative data(36). The Dr Foster Global Frailty Score was derived from these coded syndromes within this dataset, and further validated on an English national secondary care dataset (N≈7.2m). The score was significantly associated with in-hospital mortality, 30-day non-elective readmission and long length of hospital stay. The Dr Foster Global Frailty Score has significant predictive capacity beyond that of other known predictors of poor outcome in older persons, such as co-morbidity and chronological age. The score's predictive capacity was generally higher in the elective group compared with the non-elective, and may reflect improved performance in lower acuity states.

The ORs and predictive capacity in the validation cohort were generally lower than the derivation cohort, but are in keeping with other risk prediction models for older persons within the English secondary care administrative data(35, 41). There was marked variation in

volume and frequency of coding for frailty syndromes across participating countries (Figure 2). These differences may reflect different coding practices and contrasting healthcare systems. These differences may contribute to poorer performance within the validation cohort. Nevertheless, within pooled data across all participating sites, the Dr Foster Global Frailty Score appears to significantly predict in-hospital mortality and upper quartile length of stay (for country) after multivariable adjustment for age, gender, country and co-morbidity.

When both the Elixhauser co-morbidity score and Dr Foster Global Frailty Score were included within multivariable adjustment, both scores remain statistically significant for the outcomes of in-hospital mortality and upper quartile length of stay, suggesting they are not collinear.

Although the setting for the validation cohort was sourced only from English data, it was a large dataset (N=~7m spells). After multivariable adjustment for age, gender and year, the Dr Foster Global Frailty Score remained significant for all three outcomes. Predictive power was demonstrated to be similar to a previous study(35), and comparable to the derivation cohort (Table 5).

In clinical practice, risk stratification in older persons for the secondary care setting often utilise demographics (including chronological age), physiological based track-and-trigger systems (e.g. National Early Warning Score(42)), biomarkers (e.g. troponin) and understanding about the prognosis of specific disease states(e.g. co-morbidity). When adjusting for case-mix between systems or at organisational level, registry(43) or administrative(28) data are often employed, as large scale high quality data from patient records are not readily available. Consequently, risk prediction models using administrative data have sought to differentiate risk by using diagnostic(27-30), procedural(31, 32) and more recently, prescribing codes(29, 33).

There are several risk models in the United States utilising frailty-specific groups of diagnostic codes within Medicare administrative data, Medicare Current Beneficiary Survey (MCBS) data and Veteran's Affairs (VA) administrative data. Examples of these risk prediction models include Johns Hopkins Adjusted Clinical Groups (ACG, Johns Hopkins University) frailty-defining diagnoses indicator(28) and High-Risk Diagnosis for the Elderly Scale(30). In the UK, studies exploring case-mix adjustment for older persons using administrative data have utilised HES as a data source, with diagnostic groups for multimorbidity(38) and complexity(44), as well as frailty(35, 41) being tested in the literature. Appendix 4 summarises the characteristics, setting, data sources, predictor and outcome

variables and performance of recent case-mix studies for older persons utilising administrative data. Where predictive capacity is known, the Dr Foster Global Frailty Score performs comparably if not favourably.

Our study benefits from being a large multicentre international study across Europe, Australia and the United States that utilised routinely collected administrative data with the aim of case-mix adjustment for older persons in secondary care. The datasets represent whole populations, and there was little missing data. Our study employed robust statistical methods and included validation of the Dr Foster Global Frailty Score on an external dataset. It expands the diagnostic coding, provides external validation for a previous UK study(35) and extends it to include elective patients. Additionally, our model's predictive capacity is not improved on by a recent UK study(41), and its predictive capacity is arguably more uniform across the three outcomes.

However, some limitations warrant mention. The variability in frequency of coding of frailty syndromes across countries may limit reliability and generalisability, although the country of origin was accounted for in the multivariable regression. Further subgroup analysis in countries with similar frequency of coding, or hierarchical regression to account for clusters, may be the next step. The accuracy of coding in administrative data has been challenged, and sampling of local clinical units was not feasible. The Dr Foster Global Frailty Score was based on diagnostic codes and thus did not fully encompass all dimensions of frailty such as functional and socio-environmental measures as these are not well coded in the administrative data at this time. Future work linking the datasets to pharmacy, social care, primary care and registry data may provide for a richer comprehensive case-mix adjustment. A small proportion of the validation cohort may have been duplicated from the derivation cohort (eight hospitals in calendar year 2013). However, using national data from several calendar years minimises the effect of this overlap.

Our study adds to the existing literature regarding the secondary use of administrative data for case-mix adjustment in general, and for hospitalised older persons in particular. It links the clinically valid concept of frailty syndromes to a reproducible method of measurement within administrative datasets. The Dr Foster Global Frailty Score may potentially be used to routinely identify older persons at risk of adverse outcomes for the purposes of targeted resource allocation, commissioning or service development. It may form the basis of a global comparator of risk adjustment for older persons.

Conclusion

Frailty Syndromes can be feasibly coded in international secondary care administrative datasets. The Dr Foster Global Frailty Score based on coded frailty syndromes significantly predicts in-hospital mortality and upper quartile length of stay in international datasets, and additionally 30-day non-elective readmission in England's national hospital dataset. It has predictive power beyond that of the Elixhauser co-morbidity score within these datasets. This methodology may be feasibly utilised for case-mix adjustment for older persons across the international setting.

Figures Legend

Figure 1: Example of 2-step multivariable logistic regression process for the outcome of upper quartile length of stay.

Figure 2a: Percentage Volume of patients aged ≥ 75 year to total volume by country and year within Global Comparators Dataset

Figure 2b: Frequency of coding for frailty syndromes by country for year 2013 within Global Comparators Dataset (colour scale by country) in patients aged ≥ 75 years

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This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors

Competing interest statement

CP has shares in Fidelity Health, has been a consultant for Merck and the Institute for Healthcare Improvement.

Ethics approval

As per Governance Arrangements for Research Ethics Committees (GAfREC), research limited to secondary use of information previously collected in the course of normal care (without an intention to use it for research at the time of collection), provided that the patients or service users are not identifiable to the research team in carrying out the research.

Patient and Public Involvement

Patients were not involved in this study

Authors contribution

JTYS conceived study, designed analysis, interpreted results and wrote first draft. AH conceived study, designed analysis, interpreted results. JK, DL, CP and CC designed analysis, interpreted results and contributed to ongoing writing. AB and DB interpreted results and contributed to ongoing writing.

Data Sharing

No supplementary data sharing

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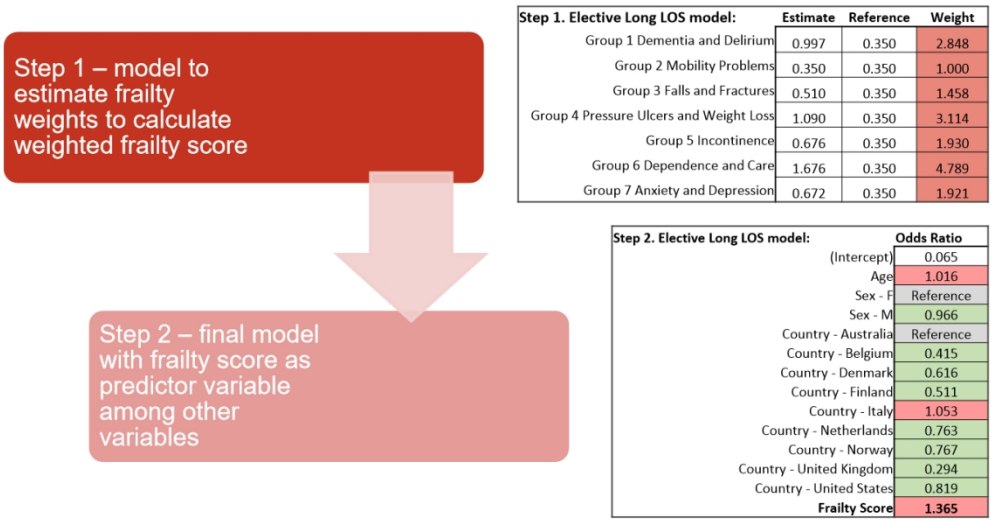
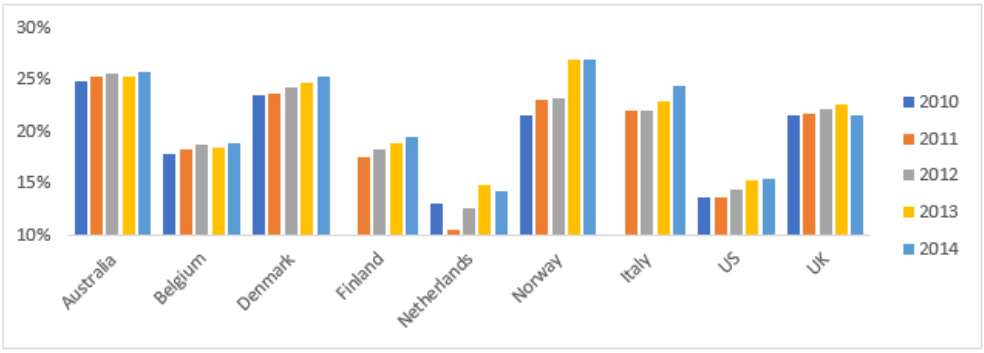


Step 1. Elective Long LOS model:	Estimate	Reference	Weight
Group 1 Dementia and Delirium	0.997	0.350	2.848
Group 2 Mobility Problems	0.350	0.350	1.000
Group 3 Falls and Fractures	0.510	0.350	1.458
Group 4 Pressure Ulcers and Weight Loss	1.090	0.350	3.114
Group 5 Incontinence	0.676	0.350	1.930
Group 6 Dependence and Care	1.676	0.350	4.789
Group 7 Anxiety and Depression	0.672	0.350	1.921

Step 2. Elective Long LOS model:	Odds Ratio
(Intercept)	0.065
Age	1.016
Sex - F	Reference
Sex - M	0.966
Country - Australia	Reference
Country - Belgium	0.415
Country - Denmark	0.616
Country - Finland	0.511
Country - Italy	1.053
Country - Netherlands	0.763
Country - Norway	0.767
Country - United Kingdom	0.294
Country - United States	0.819
Frailty Score	**1.365**

Figure 1: Example of 2-step multivariable logistic regression process for the outcome of upper quartile length of stay.

240x126mm (144 x 144 DPI)



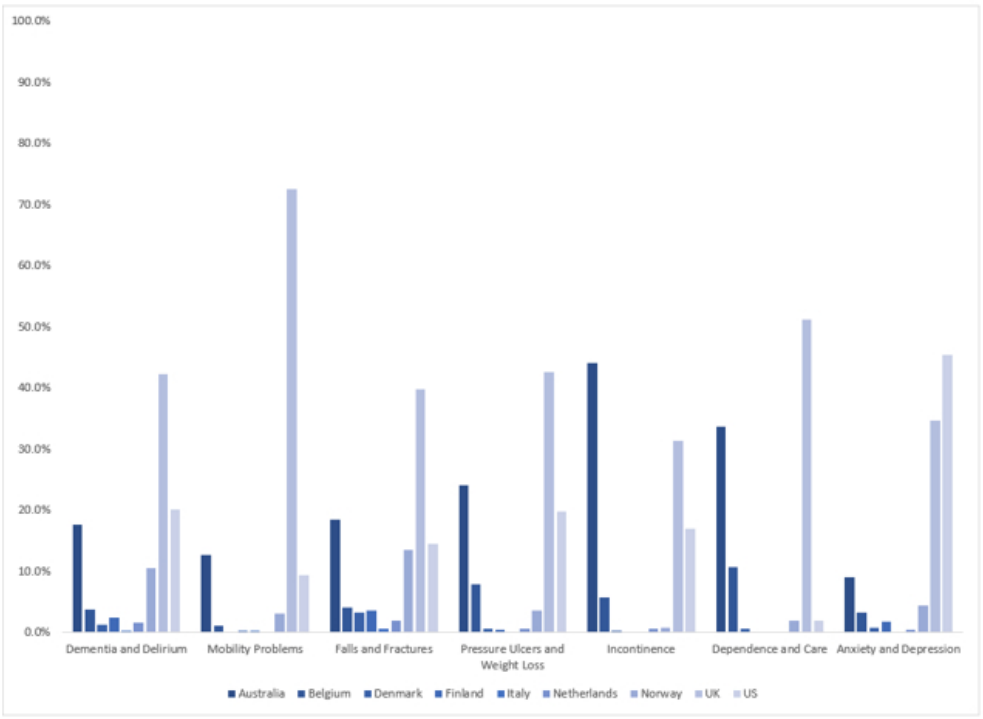


Figure 2a: Percentage Volume of patients aged ≥ 75 year to total volume by country and year within Global Comparators Dataset

Figure 2b: Frequency of coding for frailty syndromes by country for year 2013 within Global Comparators Dataset (colour scale by country) in patients aged ≥ 75 years

114x125mm (144 x 144 DPI)

Appendix 1 ICD-10 and ICD-9 coding for frailty syndromes

Group	ICD -10	Description (ICD-10)	ICD-9	Description (ICD-9)
1. Dementia and Delirium	F00	Dementia in Alzheimer's disease	2904	Arteriosclerotic dementia
	F01	Vascular dementia	2941-2942	Dementia in other diseases and unspecified dementia
	F02	Dementia in other diseases classified elsewhere	2930-2931	Subacute delirium and delirium due to conditions classified elsewhere
	F03	Unspecified dementia	V4031	Wandering in diseases classified elsewhere
	F05	Delirium not induced by alcohol and other psychoactive	3310	Alzheimer's disease
	G30	Alzheimer's disease	3312	Senile degeneration of brain
	G31 1	Senile degeneration of brain, not elsewhere classified	2900-2903	Senile and presenile dementia, dementia with delirium
	G31 0	Circumscribed brain atrophy	33119	Other frontotemporal dementia
	F04	Organic amnesic syndrome, not induced by alcohol and other psychoactive substances	33182	Dementia with lewy bodies
	R41	Other symptoms and signs involving cognitive functions and awareness	2908-2909	Other senile psychotic conditions
			2948-2949	Other persistent mental disorders due to conditions classified elsewhere
			2940	Amnestic disorder in conditions classified elsewhere
2. Mobility Problems	R26	Abnormalities of gait and mobility	7812	Abnormality of gait
	R29 8	Other and unspecified symptoms and signs involving the nervous and musculoskeletal systems	78199	Other symptoms involving nervous and musculoskeletal systems
3. Falls and Fractures	S32	Fracture of lumbar spine and pelvis	8054-8055	Fracture of lumbar vertebra without mention of spinal cord injury
	S33	Dislocation, sprain and strain of joints and ligaments of lumbar spine and pelvis	8064-8065	Fracture of lumbar spine with spinal cord injury
	S42	Fracture of shoulder and upper arm	8056-8057	Fracture of sacrum and coccyx without mention of spinal cord injury
	S43	Dislocation, sprain and strain of joints and ligaments of shoulder girdle	8066-8067	Fracture of sacrum & coccyx with spinal cord injury
	S52	Fracture of forearm	808-809	Fracture of pelvis and Ill-defined fractures of bones of trunk
	S53	Dislocation, sprain and strain of joints and ligaments of elbow	8392-8393	Dislocation, thoracic & lumbar vertebra
	S62	Fracture at wrist and hand level	83941 - 83952	Dislocation, coccyx and sacrum
	S63	Dislocation, sprain and strain of joints and ligaments at wrist and hand level	846	Sprains & strains of sacroiliac region
	S72	Fracture of femur	8472-8474	Sprain of lumbar, sacrum, coccyx
	S73	Dislocation, sprain and strain of joint and ligaments of hip	8485	Sprain of pelvic
	W0-W1	Falls	810-812	Fracture of clavicle, scapula, humerus
	M80	Osteoporosis with pathological fracture	831-835	Dislocation of shoulder, elbow, wrist, finger, hip
	M81	Osteoporosis without pathological fracture	840-843	Sprains & strains of shoulder, upper arm, elbow, forearm, wrist, hand, hip, thigh
	R296	Tendency to fall, not elsewhere classified	83961 & 83971	Dislocation, sternum
	R55	Syncope and collapse	8484	Sternum sprain
	R54	Senility	813-817	Fracture of radius & ulna, carpal bone(s), metacarpal bone(s), phalanges of hand
	M9 66	Fracture of bone following insertion of orthopaedic implant, joint prosthesis, or bone plate	820-821	Fracture of neck of femur and other parts of femur
			E88	Falls

			7330	Osteoporosis
			7331	Pathological fracture
			V1588	History of fall
			7802	Syncope and collapse
			797	Senility without mention of psychosis
			9964	Mechanical complication of internal orthopedic device implant and graft
4. Pressure Ulcers and Weight Loss	L89	Decubitus ulcer and pressure area	7072	Pressure ulcer
	R634	Abnormal weight loss	7070	Decubitus ulcer
	R636	Insufficient intake of food and water due to self neglect	7832	Abnormal Loss of Weight
	Z724	Inappropriate diet and eating habits	V691	Inappropriate diet and eating habits
5. Incontinence	R32	Unspecified urinary incontinence	7883	Incontinence of urine
	R15	Faecal incontinence	7876	Incontinence of feces
6. Dependence and Care	Z74	Problems related to care-provider dependency	V604	No other household member able to render care
	Z75	Problems related to medical facilities and other health care	V63	Unavailability of other medical facilities for care
7. Anxiety and Depression	F38	Other mood [affective] disorders	2969	Other & unspecified affective psychoses
	F41	Other anxiety disorders	3000	Anxiety states
	F43	Reaction to severe stress, and adjustment disorders	308	Acute reaction to stress
	F44	Dissociative [conversion] disorders	309	Adjustment reaction
	F064	Organic anxiety disorder	3001	Hysteria
	F32	Depressive episode	2962	Major depressive disorder, single episode
	F33	Recurrent depressive disorder	2963	Major depressive disorder, recurrent episode
	F204	Post-schizophrenic depression	2965	Bipolar affective disorder, depressed
	F251	Schizoaffective disorder, depressive type	3004	Dysthymic disorder
	F31	Bipolar affective disorder	3090	Adjustment disorder with depressed mood
	F341	Dysthymia	3091	Prolonged depressive reaction
	F412	Mixed anxiety and depressive disorder	3092	Adjustment reaction with predominant disturbance of other emotions
	F432	Adjustment disorders	2968	Manic-depressive psychosis, other & unspecified
			2980	Depressive type psychosis
			3011	Affective personality disorder
			311	Depressive disorder, not elsewhere classified

Appendix 2: Odds Ratios for Frailty Score after adjustment for age, gender, country for the outcomes of in-hospital mortality, 30-day non-elective readmission and upper quartile length of stay (for country), by elective and non-elective population groups within the Global Comparators Dataset (Derivation)

In-hospital mortality

Table 12: Odds Ratios of Frailty Score for in-hospital mortality adjusted for age, gender country within each subgroup (elective and non-elective)

Elective

	Odds Ratio	Lower CI	Upper CI	P-value
(Intercept)	0.001	0.000	0.001	<0.001
Age	1.041	1.029	1.054	<0.001
Sex - F	Reference			
Sex - M	1.441	1.277	1.626	<0.001
Country - Australia	Reference			
Country - Belgium	1.039	0.836	1.292	0.730
Country - Denmark	0.913	0.668	1.248	0.569
Country - Finland	0.318	0.227	0.446	<0.001
Country - Italy	0.702	0.496	0.994	0.046
Country - Netherlands	1.413	1.107	1.803	0.005
Country - Norway	0.616	0.492	0.770	<0.001
Country - United Kingdom	0.566	0.467	0.686	<0.001
Country - United States	0.838	0.686	1.023	0.082
Frailty Score	1.277	1.247	1.308	<0.001

Non-elective

	Odds Ratio	Lower CI	Upper CI	P-value
(Intercept)	0.002	0.002	0.003	<0.001
Age	1.040	1.037	1.043	<0.001
Sex - F	Reference			
Sex - M	1.305	1.265	1.346	<0.001
Country - Australia	Reference			
Country - Belgium	1.338	1.213	1.478	<0.001
Country - Denmark	1.480	1.371	1.598	<0.001
Country - Finland	0.936	0.864	1.015	0.109
Country - Italy	1.682	1.462	1.936	<0.001
Country - Netherlands	1.525	1.361	1.709	<0.001
Country - Norway	1.001	0.942	1.062	0.987
Country - United Kingdom	1.492	1.419	1.570	<0.001
Country - United States	0.897	0.844	0.953	<0.001
Frailty Score	1.109	1.103	1.116	<0.001

30-day non-elective readmission

Table 13: Odds Ratios of Frailty Score for 30-day non-elective readmission adjusted for age, gender country within each subgroup (elective and non-elective)

Elective

	Odds Ratio	Lower CI	Upper CI	P-value
(Intercept)	0.037	0.021	0.065	<0.001
Age	1.002	0.995	1.009	0.622
Sex - F	Reference			
Sex - M	1.159	1.087	1.236	<0.001
Country - Australia	Reference			
Country - Belgium	0.893	0.758	1.053	0.179
Country - Denmark	1.573	1.339	1.847	<0.001
Country - Finland	1.153	1.003	1.326	0.045
Country - Italy	0.500	0.391	0.640	<0.001
Country - Netherlands	1.174	0.988	1.395	0.068
Country - Norway	1.616	1.434	1.821	<0.001
Country - United Kingdom	1.094	0.975	1.228	0.125
Country - United States	1.323	1.168	1.498	<0.001
Admission History	1.453	1.411	1.495	<0.001
Frailty Score	1.106	1.060	1.154	<0.001

Non-elective

	Odds Ratio	Lower CI	Upper CI	P-value
(Intercept)	0.112	0.091	0.136	<0.001
Age	0.998	0.996	1.001	0.201
Sex - F	Reference			
Sex - M	1.167	1.137	1.198	<0.001
Country - Australia	Reference			
Country - Belgium	0.803	0.722	0.893	<0.001
Country - Denmark	1.317	1.231	1.408	<0.001
Country - Finland	0.995	0.931	1.063	0.879
Country - Italy	0.760	0.646	0.893	0.001
Country - Netherlands	0.774	0.683	0.877	<0.001
Country - Norway	1.582	1.507	1.660	<0.001
Country - United Kingdom	1.362	1.302	1.425	<0.001
Country - United States	1.274	1.211	1.340	<0.001
Admission History	1.315	1.303	1.326	<0.001
Frailty Score	1.056	1.031	1.082	<0.001

Upper Quartile Length of Stay (for country)

Table 14: Odds Ratios of Frailty Score for Upper Quartile Length of Stay (for country) adjusted for age, gender country within each subgroup (elective and non-elective)

Elective

	Odds Ratio	Lower CI	Upper CI	P-value
(Intercept)	0.065	0.045	0.094	<0.001
Age	1.016	1.011	1.020	<0.001
Sex - F	Reference			
Sex - M	0.966	0.927	1.008	0.112
Country - Australia	Reference			
Country - Belgium	0.415	0.376	0.457	<0.001
Country - Denmark	0.616	0.549	0.691	<0.001
Country - Finland	0.511	0.467	0.558	<0.001
Country - Italy	1.053	0.953	1.162	0.310
Country - Netherlands	0.763	0.691	0.843	<0.001
Country - Norway	0.767	0.713	0.825	<0.001
Country - United Kingdom	0.294	0.273	0.316	<0.001
Country - United States	0.819	0.765	0.878	<0.001
Frailty Score	1.365	1.347	1.382	<0.001

Non-elective

	Odds Ratio	Lower CI	Upper CI	P-value
(Intercept)	0.284	0.245	0.330	<0.001
Age	0.995	0.993	0.996	<0.001
Sex - F	Reference			<0.001
Sex - M	1.055	1.034	1.076	<0.001
Country - Australia	Reference			<0.001
Country - Belgium	1.766	1.658	1.881	<0.001
Country - Denmark	1.570	1.492	1.652	<0.001
Country - Finland	1.705	1.628	1.786	<0.001
Country - Italy	2.270	2.074	2.484	<0.001
Country - Netherlands	2.268	2.112	2.435	<0.001
Country - Norway	1.303	1.254	1.353	<0.001
Country - United Kingdom	1.508	1.459	1.559	<0.001
Country - United States	1.434	1.382	1.488	<0.001
Frailty Score	1.199	1.194	1.205	<0.001

Appendix 3: Odds Ratios for Frailty Score after adjustment for age, gender, calendar year for the outcomes of in-hospital mortality, 30-day non-elective readmission and upper quartile length of stay (for country), by elective and non-elective population groups in Hospital Episode Statistics dataset (Validation)

In-hospital mortality

Table 15: Odds Ratios of Frailty Score for in-hospital mortality adjusted for age, gender and calendar year within each subgroup (elective and non-elective)

Elective

	Odds Ratio	Lower CI	Upper CI	Z-value	P-value
(Intercept)	0.001	0.001	0.001	-338.153	0.000
Age	1.051	1.050	1.051	206.705	0.000
Sex - F	Reference				
Sex - M	1.274	1.267	1.281	84.839	0.000
Calendar Year - 2012	Reference				
Calendar Year - 2013	0.938	0.931	0.945	-16.172	0.000
Calendar Year – 2014	0.851	0.844	0.857	-40.603	0.000
Calendar Year – 2015	0.865	0.858	0.871	-36.727	0.000
Frailty Score	1.173	1.171	1.174	279.196	0.000

Non-elective

	Odds Ratio	Lower CI	Upper CI	Z-value	P-value
(Intercept)	0.001	0.001	0.001	-353.600	0.000
Age	1.055	1.055	1.056	227.822	0.000
Sex - F	Reference				
Sex - M	1.233	1.226	1.240	73.302	0.000
Calendar Year - 2012	Reference				
Calendar Year - 2013	0.936	0.929	0.944	-16.598	0.000
Calendar Year – 2014	0.850	0.844	0.857	-40.640	0.000
Calendar Year – 2015	0.869	0.862	0.876	-35.371	0.000
Frailty Score	1.108	1.107	1.109	315.847	0.000

30-day non-elective readmission

Table 16: Odds Ratios of Frailty Score for 30-day non-elective readmission adjusted for age, gender and calendar year within each subgroup (elective and non-elective)

Elective

	Odds Ratio	Lower CI	Upper CI	Z-value	P-value
(Intercept)	0.055	0.054	0.057	-186.458	0.000
Age	1.011	1.010	1.011	58.247	0.000
Sex - F	Reference				
Sex - M	1.119	1.114	1.123	53.787	0.000
Calendar Year - 2012	Reference				
Calendar Year - 2013	0.994	0.989	1	-1.918	0.055
Calendar Year – 2014	1.015	1.009	1.021	5.090	0.000
Calendar Year – 2015	1.018	1.012	1.024	6.228	0.000
Previous Emergency Admissions	1.443	1.440	1.445	379.358	0.000
Frailty Score	1.045	1.044	1.047	77.860	0.000

Non-elective

	Odds Ratio	Lower CI	Upper CI	Z-value	P-value
(Intercept)	0.053	0.051	0.054	-191.317	0.000
Age	1.011	1.011	1.012	62.570	0.000
Sex - F	Reference				
Sex - M	1.121	1.117	1.126	54.752	0.000
Calendar Year - 2012	Reference				
Calendar Year - 2013	0.993	0.987	0.998	-2.526	0.012
Calendar Year – 2014	1.012	1.007	1.018	4.231	0.000
Calendar Year – 2015	1.015	1.010	1.021	5.218	0.000
Previous Emergency Admissions	1.439	1.436	1.442	376.406	0.000
Frailty Score	1.030	1.030	1.031	85.172	0.000

Upper quartile length of stay

Table 17: Odds Ratios of Frailty Score for upper quartile length of stay adjusted for age, gender and calendar year within each subgroup (elective and non-elective)

Elective

	Odds Ratio	Lower CI	Upper CI	Z-value	P-value
(Intercept)	0.030	0.029	0.031	-258.331	0.000
Age	1.023	1.023	1.024	143.925	0.000
Sex - F	Reference				
Sex - M	0.940	0.937	0.944	-32.930	0.000
Calendar Year - 2012	Reference				
Calendar Year - 2013	0.975	0.970	0.980	-9.874	0.000
Calendar Year – 2014	0.891	0.886	0.895	-44.736	0.000
Calendar Year – 2015	0.872	0.868	0.877	-52.705	0.000
Frailty Score	1.193	1.192	1.193	593.715	0.000

Non-elective

	Odds Ratio	Lower CI	Upper CI	Z-value	P-value
(Intercept)	0.031	0.030	0.032	-255.862	0.000
Age	1.023	1.022	1.023	139.087	0.000
Sex - F	Reference				
Sex - M	0.948	0.944	0.951	-28.576	0.000
Calendar Year - 2012	Reference				
Calendar Year - 2013	0.979	0.974	0.984	-8.288	0.000
Calendar Year – 2014	0.896	0.891	0.900	-42.538	0.000
Calendar Year – 2015	0.878	0.874	0.883	-50.020	0.000
Frailty Score	1.055	1.055	1.055	602.049	0.000

Appendix 4 Case-mix adjustment for older persons utilising administrative data

Author	Year	Country	Study population	N	Data Source	Outcome	Predictors	Model performance
Von Korff et al.(1)	1991	United States	Population based pharmacy data	122911	Administrative	Mortality and hospitalisation	Consensus based Chronic Disease Score(CDS)	
Rosen et al.(2)	2001	United States	Long-term facility resident (Veterans Affairs)	39839	Administrative (Patient Assessment File(PAF), Patient Treatment File(PTF), Extended Care File(ECF))	Decline in functional status	International Classification of Diseases, Ninth Revision Clinical Modification (ICD-9) , demographics, treatments, activities of daily living	AUC for decline in functional status is 0.70
Desai et al.(3)	2002	United States	≥70 admitted to geriatric service	1376	Administrative (Management Information System)	Mortality	International Classification of Diseases system, version 9 (ICD-9)	AUC 0.76 for mortality in derivation and AUV 0.68 in validation)
Kautter et al(4)	2004	United States	Medicare	17597	Administrative The Medicare Current Beneficiary Survey (MCBS)	Cost	ADLs, Long-term institution status, Age	
Roland et al.(5)	2005	United Kingdom	Individual patients aged ≥ 65, ≥ 75, and ≥ 85who had at least two emergency admissions	227206	Administrative (Hospital Episode Statistics)	Non-elective hospital readmission	Individual patients aged ≥ 65who had at least two emergency admissions	

Inoye et al.(6)	2008	United States	Primary care clinic	3919	Administrative	Non-elective hospital admission	Deyo-Charlson comorbidity score ≥ 1, any prior hospitalization, 6 or more primary care visits, ≥ 85 years unmarried status	AUC 0.73
Sternberg et al.(7)	2012	Israel	Patients receiving Comprehensive Geriatric Assessment via OPD	221	Administrative; and survey	Resource utilisation (number of physician visits in 3 months, number of ED visits in a year, and number of hospitalizations in the year)	VES Frailty Score(13-item function-based self-report questionnaire), Adjusted Clinical Groups diagnoses based predictive model (ACG Dx-PM) based on age, sex, diagnostic codes, and pharmacy data	ACG predict frailty defined by VES – AUC 0.63
Davidoff et al.(8)	2013	United States	US Medicare beneficiaries aged ≥ 65 years	14788	Administrative (Medicare) and Medicare Current Beneficiary Survey (MCBS),	Disability Status	Healthcare services, Berenson-Eggers Type of Service (BETOS) codes, American Medical Association's Current Procedural Terminology (CPT) codes, or the ICMP, Healthcare Common Procedure Coding System (HCPCS level II) codes, demographic	AUC 0.92 for disability status
Bottle et al.(9)	2014	United Kingdom	Admitted with heart failure	84212	Administrative (Hospital Episode statistics)	Non-elective hospital readmission	AHRQ's (Agency for Healthcare Research and Quality) Clinical Classification System International Classification of Diseases system version 10 (ICD-10)	
Chrischilles et al.(10)	2014	United States	US Medicare beneficiaries aged ≥ 65 years admitted with acute	144112	Administrative	Mortality, cardiac catheterisation	Demographic measures, cardiovascular conditions, comorbidities, previous hospitalization, and Function related indicators(FRI)	AUC Mortality 0.74, AUC cardiac catheterisation 0.79, Including the FRIs improved

			myocardial infarction					prediction models
Ruiz et al.(11)	2015	United Kingdom	Individual patients aged ≥ 65 with hospital admission	2788900	Administrative (Hospital Episode Statistics)	Mortality, Non-elective hospital readmission, Hospital admission	≥ 65 years old who have at least 3 simultaneous diagnoses of major clinical conditions.	
Faurot et al.(12)	2015	United States	≥ 65 community dwelling	6391	Administrative and Medicare Current Beneficiary Survey (MCBS)	Functional decline	demographics, International Classification of Diseases, Ninth Revision Clinical Modification (ICD-9) diagnosis/procedure and durable medical equipment codes for frailty-associated conditions, (Current Procedural Terminology (CPT) and Healthcare Common Procedure Coding System (HCPC))	
Hope et al.(13)	2015	United States	>70 admitted to ICU	47427	Administrative (Medicare)	Mortality	International Classification of Diseases, Ninth Revision Clinical Modification (ICD-9) diagnosis & claims for skilled nursing facility: creation of four categories: 1)Cancer 2)Chronic Organ Failure3)Frailty4) Robust	
Soong et al.	2015	United Kingdom	>65 non-elective admission to hospital	2 099 252	Administrative	Mortality, non-elective readmission, functional decline	ICD-10 codes, Frailty Syndromes	AUC of 0.624–0.659 for inpatient mortality, 0.63–0.654 for institutionalisation and 0.57–0.63 for 30-day

								emergency readmission.
Briggs et al.(14)	2016	Ireland	Patients admitted with dementia to single hospital	929	Administrative	Cost	International Classification of Diseases system version 10 (ICD-10)	
McIsaac et al.(15)	2016	Canada	>65 years Elective non-cardiac surgery	202811	Administrative Discharge Abstract Database, Ontario Health Insurance Plan Database, Registered Persons Database	Inpatient mortality	John's Hopkins Adjusted Clinical Groups (ACG, Johns Hopkins University) frailty-defining diagnoses indicator,	
Kim et al.(16)	2017	United States	≥ 65 community dwelling	10017	Administrative (Medicare) and Medicare Current Beneficiary Survey (MCBS)	Mortality, disability, mobility impairment, and recurrent falls	International Classification of Diseases, Ninth Revision Clinical Modification (ICD-9) (Current Procedural Terminology (CPT) and Healthcare Common Procedure Coding System (HCPC)) to create a frailty index	
Gilbert et al.(17)	2018	United Kingdom	>75 years elective and non-elective admissions to hospital	1 013 590	Administrative Hospital Episode Statistics	Mortality, long length of stay, non-elective readmission	ICD-10 Codes identified by cluster analysis for Bed days, Hospital costs, and ICD-10 coded Frailty Syndromes	AUC 0·60 for 30-day mortality, 0·68 for long hospital stay, 0·56 for 30-day readmission.

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TRIPOD Checklist: Prediction Model Development and Validation

Section/Topic	Item		Checklist Item	Page
Title and abstract				
Title	1	D;V	Identify the study as developing and/or validating a multivariable prediction model, the target population, and the outcome to be predicted.	2
Abstract	2	D;V	Provide a summary of objectives, study design, setting, participants, sample size, predictors, outcome, statistical analysis, results, and conclusions.	3
Introduction				
Background and objectives	3a	D;V	Explain the medical context (including whether diagnostic or prognostic) and rationale for developing or validating the multivariable prediction model, including references to existing models.	5
	3b	D;V	Specify the objectives, including whether the study describes the development or validation of the model or both.	5
Methods				
Source of data	4a	D;V	Describe the study design or source of data (e.g., randomized trial, cohort, or registry data), separately for the development and validation data sets, if applicable.	6
	4b	D;V	Specify the key study dates, including start of accrual; end of accrual; and, if applicable, end of follow-up.	6-7
Participants	5a	D;V	Specify key elements of the study setting (e.g., primary care, secondary care, general population) including number and location of centres.	7
	5b	D;V	Describe eligibility criteria for participants.	7
	5c	D;V	Give details of treatments received, if relevant.	NA
Outcome	6a	D;V	Clearly define the outcome that is predicted by the prediction model, including how and when assessed.	9
	6b	D;V	Report any actions to blind assessment of the outcome to be predicted.	NA
Predictors	7a	D;V	Clearly define all predictors used in developing or validating the multivariable prediction model, including how and when they were measured.	8-9, App 1
	7b	D;V	Report any actions to blind assessment of predictors for the outcome and other predictors.	NA
Sample size	8	D;V	Explain how the study size was arrived at.	7
Missing data	9	D;V	Describe how missing data were handled (e.g., complete-case analysis, single imputation, multiple imputation) with details of any imputation method.	7
Statistical analysis methods	10a	D	Describe how predictors were handled in the analyses.	8-10
	10b	D	Specify type of model, all model-building procedures (including any predictor selection), and method for internal validation.	8-10
	10c	V	For validation, describe how the predictions were calculated.	8-10
	10d	D;V	Specify all measures used to assess model performance and, if relevant, to compare multiple models.	10
	10e	V	Describe any model updating (e.g., recalibration) arising from the validation, if done.	NA
Risk groups	11	D;V	Provide details on how risk groups were created, if done.	NA
Development vs. validation	12	V	For validation, identify any differences from the development data in setting, eligibility criteria, outcome, and predictors.	6-7
Results				
Participants	13a	D;V	Describe the flow of participants through the study, including the number of participants with and without the outcome and, if applicable, a summary of the follow-up time. A diagram may be helpful.	11, 15
	13b	D;V	Describe the characteristics of the participants (basic demographics, clinical features, available predictors), including the number of participants with missing data for predictors and outcome.	11
	13c	V	For validation, show a comparison with the development data of the distribution of important variables (demographics, predictors and outcome).	15-16
Model development	14a	D	Specify the number of participants and outcome events in each analysis.	11-14 App 2-3
	14b	D	If done, report the unadjusted association between each candidate predictor and outcome.	NA
Model specification	15a	D	Present the full prediction model to allow predictions for individuals (i.e., all regression coefficients, and model intercept or baseline survival at a given time point).	11-14 App 2-3
	15b	D	Explain how to the use the prediction model.	NA
Model performance	16	D;V	Report performance measures (with CIs) for the prediction model.	15-16
Model-updating	17	V	If done, report the results from any model updating (i.e., model specification, model performance).	NA
Discussion				
Limitations	18	D;V	Discuss any limitations of the study (such as nonrepresentative sample, few events per predictor, missing data).	18
Interpretation	19a	V	For validation, discuss the results with reference to performance in the development data, and any other validation data.	16-17
	19b	D;V	Give an overall interpretation of the results, considering objectives, limitations, results from similar studies, and other relevant evidence.	16-18 App 4
Implications	20	D;V	Discuss the potential clinical use of the model and implications for future research.	18-19
Other information				
Supplementary information	21	D;V	Provide information about the availability of supplementary resources, such as study protocol, Web calculator, and data sets.	App 1-4
Funding	22	D;V	Give the source of funding and the role of the funders for the present study.	19

TRIPOD Checklist: Prediction Model Development and Validation

*Items relevant only to the development of a prediction model are denoted by D, items relating solely to a validation of a prediction model are denoted by V, and items relating to both are denoted D;V. We recommend using the TRIPOD Checklist in conjunction with the TRIPOD Explanation and Elaboration document.

BMJ Open

The Dr Foster Global Frailty Score: An international retrospective observational study developing and validating a risk prediction model for hospitalised older persons from administrative datasets.

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Primary Subject Heading:	Geriatric medicine
Secondary Subject Heading:	Diagnostics, Global health, Health informatics, Health policy, Health services research
Keywords:	Frailty, Secondary Care, Measure, Administrative, Risk Prediction

Title: The Dr Foster Global Frailty Score: An international retrospective observational study developing and validating a risk prediction model for hospitalised older persons from administrative datasets.

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Structured abstract 300 words. (300 words)

Objectives. This study aimed to examine the prevalence of frailty coding within the Dr Foster Global Comparators (GC) international database. We then aimed to develop and validate a risk prediction model, based on frailty syndromes, for key outcomes using the GC dataset.

Design. A retrospective cohort analysis of data from patients over 75 years of age from the GC international administrative data. A risk prediction model was developed from the initial analysis based on seven frailty syndrome groups and their relationship to outcome metrics. A weighting was then created for each syndrome group and summated to create the Dr Foster Global Frailty Score. Performance of the score for predictive capacity was compared with an established prognostic comorbidity model (Elixhauser) and tested on another administrative database Hospital Episode Statistics (2011-2015), for external validation.

Setting. 34 hospitals from nine countries across Europe, Australia, the UK and USA.

Results. Of 6.7 million patient records in the GC database, 1.4 M (20%) were from patients aged 75 years or more. There was marked variation in coding of frailty syndromes between countries and hospitals. Frailty syndromes were coded in 2-24% of patient spells. Falls and fractures was the most common syndrome coded (24%). The Dr Foster Global Frailty Score was significantly associated with in-hospital mortality, 30-day non-elective readmission and long length of hospital stay. The score had significant predictive capacity beyond that of other known predictors of poor outcome in older persons, such as co-morbidity and chronological age. The score's predictive capacity was higher in the elective group compared with non-elective, and may reflect improved performance in lower acuity states.

Conclusions: Frailty Syndromes can be coded in international secondary care administrative datasets. The Dr Foster Global Frailty Score significantly predicts key outcomes. This methodology may be feasibly utilised for case-mix adjustment for older persons internationally.

Article summary – strengths and limitations of this study

- This study is a large multicentre international study across Europe, Australia and the United States utilising a routinely collected administrative data with the aim of providing a simple model for case-mix adjustment for older persons in secondary care.
- The dataset used represent whole populations, and there was little missing data.
- Robust statistical methods were used and the Dr Foster Global Frailty Score was validated on an external dataset (Hospital Episode Statistics)
- Our model's predictive capacity is comparable with other recent single country studies
- The variability in frequency of coding of frailty syndromes across countries may limit reliability and generalisability.

Introduction

Increased population ageing stems from a range of diverse factors, including lower childhood and adult mortality, improved fertility, migration, relative world peace and improved health and social care(1). For many, this phenomenon is associated with good health and quality of life(2). For others, there is increased co-morbidity(3), functional decline(4) and poorer quality of life. Differences in the health and function of individuals as they grow older is not readily explained by chronological age(5). Frailty is common and increasingly prevalent with advancing age and often defined as a decrease in physiological reserve over a life-course. Using this pathophysiological model of frailty several underlying processes have been described, including chronic inflammation(6, 7), sarcopaenia(8), anaemia(9) and coagulopathy, steroid hormone dysregulation(10, 11), low vitamin D levels, malnutrition(12, 13) and insulin resistance(14, 15) underpin frailty. These deficits can accumulate over the course of life-time exposure to environmental stressors. Frailty manifests as a combination of the pathophysiological consequence of inbuilt senescence and the accumulation of defects throughout a life-course. Frailty ultimately results in recognisable clinical manifestations such as recurrent falls and delirium and is associated with increased mortality, disability and high resource utilisation(16). Conceptually and operationally, frailty appears to be related to, but distinct from, disability, co-morbidity and chronological age(17). The importance of contributing environmental factors and the psycho-social impact of frailty are increasingly being recognised(18) as important.

Assessing frailty in the hospital setting is challenging. Many frailty assessment scores tested have poor reliability, require large amounts of data, or specialised equipment and have poor predictive performance(19). Given these limitations, there is increasing interest in utilising routinely collected administrative data for risk prediction modelling for those at risk of frailty, particularly older persons. Risk prediction models estimate the likelihood of developing a specific outcome, or having a specific condition. These models can be utilised for the purposes of case-mix adjustment or risk-stratification. Case-mix risk adjustment allows for more accurate comparison of organisational performance by reducing confounding bias. For example, when considering mortality as an outcome measure for organisations, patient-specific factors such as illness severity influence outcome, and must be taken into account. Risk stratification allows for possible segmentation of a population into different levels of risk for developing a specific outcome. This segmentation can then be used to health system planning or inform targeting of resources.

In older persons, risk prediction models often utilise chronological age(20), co-morbidity(21) and functional dependence(22) as patient-specific factors for risk prediction. In the context of long-term care (e.g. nursing homes), risk prediction models often utilise functional dependence as a patient factor, to aid appropriate health resource utilisation and costing (23-25). A recent English study in the primary care setting derived an electronic frailty index from patient records with predictive validity for nursing home admission, hospitalisation and mortality (26). In secondary care, risk prediction models for older persons have utilised measures of demographics, and co-morbidity in the form of diagnostic (27-30) and procedural codes(31, 32), as well as prescription data(29, 33). Frailty syndromes are recognised as clinical manifestations of frailty(34). These common presentations in older persons include recurrent falls, cognitive impairment, incontinence and pressure ulcers, are associated with poor outcome. Recent studies have explored the coding of frailty syndromes within secondary care administrative datasets in the United Kingdom, and its association with in-hospital mortality, non-elective readmission and functional decline.(35, 36)

In this study, we explored the prevalence of coded frailty syndromes within an international secondary care dataset to develop and validate a risk prediction model based on frailty syndromes for the outcomes of mortality, non-elective readmission and long length of stay. We sought to compare the performance of this model with an established prognostic co-morbidity model for the above outcomes.

Methods

Data Sources

The Global Comparators programme at Dr Foster® was an international hospital collaborative which ran from 2011-2017, focused on pooling and benchmarking data, knowledge-sharing networks and health services research to better understand variations in outcomes and disseminate international best practice. The hospitals within the collaboration contributed administrative data to be pooled within the Global Comparators dataset, using established data cleaning processes(37). This provided a rich patient-level dataset containing demographics, diagnostic codes, procedure codes and outcomes, collected primarily for administrative purposes, such as operational needs and costing. To develop and test Dr Foster Global Frailty Score, Global Comparators data were extracted from 34 hospitals in nine countries: Australia, Belgium, Denmark, Finland, Italy, Netherlands, Norway, United Kingdom and United States.

Hospital Episode Statistics (HES) is an English national administrative dataset, housed within the safe haven of NHS Digital, and contains administrative data from English hospital trusts, which are cleaned and securely stored. This dataset was used to validate the Dr Foster Global Frailty Score. We included the 138 English acute non-specialist hospital trusts, excluding hyper-specialist hospitals (e.g. single pathology quaternary referral units) and mental health units, which have different case-mix.

Study Population

Patient records were included in the analysis if they fulfilled the criteria of patient age ≥75 years and required an elective or non-elective hospital admission of 24 hours or more. Patient spells were excluded if the age, sex or length of stay was recorded as missing or invalid, or the admission was planned and the patient discharged home on the same day, or the admission was unplanned but no procedure was undertaken and the patient went home after recorded length of stay less than 2 days. This was to exclude records with inadequate quality data, and patients admitted into observations units or day-case attendances. Overall, 0.17% of data were missing within the derivation dataset.

Coding frailty

Each patient record corresponded to a spell covering a patient's total length of stay at a hospital. Within HES, these were aggregated into 'superspells' (admissions), which encompass the full length of stay for the patient across all hospital trusts before their final discharge. Seven groups of frailty syndromes were chosen to represent the common domains used in comprehensive geriatric assessment: Dementia and Delirium, Mobility Problems, Falls and Fractures, Pressure Ulcers and Weight Loss, Incontinence, Dependence and Care, as well as Anxiety and Depression were coded within International Statistical Classification of Diseases, Injuries and Causes of Death (ICD) diagnostic coding groups, and within all available diagnostic fields. As the Global Comparators dataset comprised hospitals which utilised different revisions of ICD (revision 9 and 10), equivalent diagnostic codes for both versions were compiled. These diagnostic coding groups were modified from previously published work on English national administrative data(35). Appendix 1 displays the full list of ICD-9 and ICD-10 diagnostic codes utilised to code for the seven frailty syndrome groups. Trends by calendar year and month, country and frailty syndrome group were plotted to investigate frequency of coding for the years 2010-2014. Based on this analysis, years 2012-2013 were selected as having stable coding for multivariable risk prediction modelling within the derivation dataset.

Table 1: Predictors inputs for frailty risk prediction model (independent predictors)

Name	Time span	Description	Comments
Age	Current spell	Age on admission	
Gender	Current spell	Gender on admission	
Country	Current Spell	Country from which hospital contributed data	Nominal; Countries were: Australia, Belgium, Denmark, Finland, Italy, Netherlands, Norway, United Kingdom, United States
Dementia & Delirium Mobility Problems Falls & Fractures Pressure Ulcers & Weight Loss Dependence and Care Anxiety & Depression	12-month historical binary indicator	A binary flag indicating whether a relevant diagnosis has been received during any inpatient spell in the past 12 months	Final Dr Foster Global Frailty Score is weighted (see risk stratification models section for further details)
Co-morbidity (Elixhauser)	12-month historical score	A weighted score (see risk stratification	Integer

		models section for further details)	
Number of previous admissions	12-month historical count	The number of emergency admission spells in the previous 12 months excluding the current spell	Integer

Table 2: Predictor outputs for frailty risk prediction model (dependent variables)

Name	**Time span**	**Description**	**Comments**
In-hospital mortality	Current spell	Indicates if the discharge method was death	
30-day non-elective readmission	30 days from discharge	Indicates if the patient had an emergency admission with admission date between 1 and 30 days following the discharge date of the index admission	Spells that ended in death are excluded from the analysis
Long length of stay	Current spell	Upper quartile length of hospital stay for country	

Risk Models

Within the Global Comparators dataset, 30 separate regression models were undertaken, to account for admission status, frailty, Elixhauser co-morbidity and combination of frailty and Elixhauser for the three outcomes above(Figure 1).. The characteristics of predictor and outcome variables included within the models are described in Tables 1 and 2. Elective and non-elective hospital admission populations were modelled separately. A two-step process for each outcome was utilised to model the frailty and comorbidity scores. First, binary logistic regression was utilised to ascertain odds ratios (ORs) for each frailty syndrome group and each outcome, within the population subgroups separately (elective and non-elective). The natural log of OR (*ln* OR) was used to create weights for each frailty syndrome group, using the smallest *ln* OR as reference (weighted 1.0). Secondly, the summation of the weights for each frailty syndrome group was utilised to create a frailty score. The patient-level frailty score was then included within a multivariable logistic regression model, adjusted for age, gender and country, for each outcome. Figure 2 illustrates an example of this two-step process for the outcome of upper quartile length of stay.

The Elixhauser co-morbidity score was calculated for each outcome using previously described methods(38). To provide comparison, the Elixhauser co-morbidity score was then included within a multivariable logistic regression model, adjusting for age, gender and country, for each outcome. Finally, both the Elixhauser co-morbidity and Dr Foster Global Frailty Score were then included within a multivariable logistic regression model, adjusted for age, gender and country, for each outcome. The predicted probabilities from these regression models were utilised to calculate Area under the Receiver Operator Characteristic Curves (AUC) as a measure of predictive capacity for each outcome. This two-step process was repeated for the Dr Foster Global Frailty Score on HES years 2011-2015 for external validation.

Performance metrics

Multicollinearity between predictor variables was investigated by variance inflation factor (VIF), where VIF scores of over three were taken to denote unacceptable collinearity. The Hosmer-Lemeshow statistic was calculated for each model to ascertain model calibration. The Wald statistic was calculated to explore the explanatory power of the Dr Foster Global Frailty Score, Elixhauser co-morbidity Score, age, country and gender for each of the three outcomes. Statistical analysis was undertaken using the R Statistical Package.

Patient and Public Involvement

Patients were not involved in this study

Results

Descriptive statistics

Of the 6,739,790 spells within the Global Comparators Database from 2010-2014, 1,366,187 (20%) involved patients aged ≥ 75 years. There was variation in frequency of coding of frailty syndromes across the countries. The four countries with most volume of coded frailty syndromes were Australia, Belgium, the United Kingdom and the United States. Figure 3a & 3b describes the percentage of spells of patients ≥ 75 years to total volume by country and year within the database, and the frequency of coding for frailty syndromes by country for the year 2013.

Coded Frailty Syndromes

Frailty syndromes were coded in 2-24% of patient spells among patients aged ≥ 75 years from 2010-2014 within the Global Comparators database: Falls and Fractures N=326,528 (24%); Dementia and Delirium N=215,629 (16%); Anxiety and Depression N=87,732 (6%); Pressure Ulcers and Weight Loss N=66,208 (5%); Incontinence N=50,277 (4%); Mobility Problems N=39,479 (3%); and Dependence and Care N=28,294 (2%). At least one frailty syndrome was present in 538,766 (39%) of spells.

Derivation Cohort

Of the 294,998 patient spells from 2012-2013 for those aged ≥ 75 years used in the predictive models within the derivation cohort from the Global Comparators Dataset, 221 441 (75%) were non-elective admissions and 158 595 were female (54%). Patient spells that ended with inpatient mortality (42,354, 14%) of were excluded from the predictive models exploring non-elective readmission.

Dr Foster Global Frailty Score

Negative scores were set to 0 and positive scores were not capped. The Dr Foster Global Frailty Score varied based on outcome and population (elective and non-elective), and remained significant after multivariable adjustment. Table 3 summarises the ORs of the Dr Foster Global Frailty Score and Elixhauser Co-morbidity Score after multivariable adjustment for age, gender and country for the outcomes of in-hospital mortality, 30-day non-elective readmission and upper quartile length of stay (for country), by elective and non-elective

population groups. Appendix 2 displays full multivariable adjustment of the Dr Foster Global Frailty Score.

Table 3: Odds ratios for Elixhauser and Dr Foster Global Frailty Score after multivariable adjustment for age, gender and country

	Outcome	Score range	Population	Odds Ratio	Lower CI	Upper CI	P-value
Dr Foster Global Frailty Score	In-hospital mortality	0-11	Elective	1.277	1.247	1.308	<0.001
		0-13	Non-elective	1.109	1.103	1.116	<0.001
	30-day non-elective readmission	0-6	Elective	1.106	1.060	1.154	<0.001
		0-4	Non-elective	1.056	1.031	1.082	<0.001
	Upper Quartile Length of Stay (for country)	0-16	Elective	1.365	1.347	1.382	<0.001
		0-17	Non-elective	1.199	1.194	1.205	<0.001
Elixhauser co-morbidity score	In-hospital mortality		Elective	1.309	1.290	1.329	<0.001
			Non-elective	1.130	1.126	1.133	<0.001
	30-day non-elective readmission		Elective	1.144	1.130	1.158	<0.001
			Non-elective	1.045	1.042	1.048	<0.001
	Upper quartile length of stay (for country)		Elective	1.101	1.097	1.105	<0.001
			Non-elective	1.069	1.068	1.071	<0.001

When both the Dr Foster Global Frailty Score and Elixhauser co-morbidity Score were included in multivariable risk adjustment models for age, gender and country, the Dr Foster Global Frailty Score remained significant for the outcomes of in-hospital mortality and upper quartile length of stay, but not for 30-day non-elective readmission (Table 4).

Table 4: Odds ratios for Elixhauser and Dr Foster Global Frailty Score after multivariable adjustment for age, gender and country with both scores in model

Outcome	Population	Score	Odds Ratio	Lower CI	Upper CI	P-value
In-hospital mortality	Elective	Elixhauser	1.283	1.263	1.304	<0.001
		Frailty	1.114	1.085	1.144	<0.001
	Non-elective	Elixhauser	1.123	1.119	1.126	<0.001
		Frailty	1.058	1.052	1.065	<0.001
30-day non-elective readmission	Elective	Admission History*	1.273	1.234	1.314	<0.001
		Elixhauser	1.142	1.128	1.157	<0.001
		Frailty	1.032	0.988	1.077	0.160
	Non-elective	Admission History*	1.240	1.228	1.252	<0.001
		Elixhauser	1.045	1.042	1.048	<0.001
		Frailty	1.024	1.000	1.049	0.052
Upper quartile length of stay	Elective	Elixhauser	1.081	1.077	1.085	<0.001
		Frailty	1.243	1.227	1.260	<0.001
	Non-elective	Elixhauser	1.055	1.053	1.056	<0.001
		Frailty	1.137	1.131	1.142	<0.001

*Admission history included in multivariable model exploring 30-day non-elective readmission

The predictive capacity of the Dr Foster Global Frailty Score and Elixhauser co-morbidity score are compared in Table 5. When the Dr Foster Global Frailty Score and Elixhauser co-morbidity score are both included in a multivariable model adjusted for age, gender and country, the predictive capacity is moderate to good. The predictive capacity of the Elixhauser co-morbidity score generally exceeds that of the Dr Foster Global Frailty Score for all three outcomes.

Table 5: Area under the Receiver Operator Statistic Curve for outcomes by Elixhauser score, Dr Foster Global Frailty Score and population within Global Comparators dataset

Global Comparators Dataset	Elixhauser		Dr Foster Global Frailty Score		Elixhauser and Dr Foster Global Frailty Score	
Outcome/AUC	Elective	Non-elective	Elective	Non-elective	Elective	Non-elective
In-hospital mortality	0.80	0.69	0.70	0.62	0.81	0.69
30-day non-elective readmission*	0.67	0.64	0.64	0.63	0.67	0.64
Upper quartile length of stay	0.72	0.63	0.69	0.61	0.73	0.65

*Admission history included in multivariable model exploring 30-day non-elective readmission

The Wald statistic for independent variables included in final models by population and outcome are displayed in Table 6. Overall, the explanatory power of the Elixhauser co-morbidity score exceeds the Dr Foster Global Frailty Score for all three outcomes.

Table 6: Wald Statistic for independent variables of final models by outcome and population

	Upper quartile length of stay		30-day non-elective readmission		In-hospital mortality	
	Elective	Non-elective	Elective	Non-elective	Elective	Non-elective
Age	31.1	31.4	0.0	0.4	46.4	747.2
Sex	18.7	0.2	6.9	77.6	9.5	85.2
Country	162.0	244.2	31.1	102.1	12.8	137.8
Admission History	-	-	225.9	1888.4	-	-
Dr Foster Global Frailty Score	1020.7	2579.9	2.0	3.8	62.7	318.2
Elixhauser Score	1727.5	4075.1	420.4	848.4	973.9	4842.1

Performance metrics

All our models displayed significance at $p<0.05$ for the Hosmer-Lemeshow tests for goodness-of-fit test. These findings have been similarly described by others who have produced models on large data sets as the test is recognised to detect unimportant differences(38, 39). None of the predictor variables demonstrated unacceptable collinearity(40).

Validation Cohort

Of the 7,195,950 patient spells from 2011-2015 used in the predictive models within the validation cohort from English national Hospital Episode Statistics data, 6,128,811 (85%) were non-elective admissions, and 564,182 (7.8%) patient spells ending with in-hospital mortality were excluded from predictive models exploring non-elective readmission.

The Dr Foster Global Frailty Score remained significant after multivariable adjustment within the validation dataset. However, the predictive capacity and ORs were generally lower across all three outcomes compared to the derivation cohort. Table 7 summarises the ORs and AUC of the Dr Foster Global Frailty Score after multivariable adjustment for age, gender and calendar year for the outcomes of in-hospital mortality, 30-day non-elective readmission and upper quartile length of stay (for country), by elective and non-elective population groups. Appendix 3 displays full multivariable adjustment of the Dr Foster Global Frailty Score within the validation dataset.

Table 7: Odds ratios and for Area under the Receiver Operator Statistic Curve (AUC) for Global Frailty Score following multivariable adjustment for age, gender, calendar year by population subgroup and outcome

Outcome	Population	AUC	Odds Ratio	Lower CI	Upper CI	P-value
In-hospital mortality	Elective	0.649	1.173	1.171	1.174	<0.001
	Non-elective	0.655	1.108	1.107	1.109	<0.001
30-day non-elective readmission	Elective	0.630	1.045	1.044	1.047	<0.001
	Non-elective	0.630	1.030	1.030	1.031	<0.001
Upper Quartile Length of Stay (for country)	Elective	0.676	1.193	1.192	1.193	<0.001
	Non-elective	0.677	1.055	1.055	1.055	<0.001

*Admission history included in multivariable model exploring 30-day non-elective readmission

Discussion

Our study found that frailty syndromes are coded with variable frequency within a large (N≈1.3m) international dataset of hospitalised older persons (aged over 75 years) utilising readily available administrative data, with Falls & Fractures and Dementia & Delirium being the most frequently coded syndromes. This is consistent with a previous study using English administrative data(36). The Dr Foster Global Frailty Score was derived from these coded syndromes within this dataset, and further validated on an English national secondary care dataset (N≈7.2m). The score was significantly associated with in-hospital mortality, 30-day non-elective readmission and long length of hospital stay. The score's predictive capacity was generally higher in the elective group compared with the non-elective, and may reflect improved performance in lower acuity states.

The ORs and predictive capacity in the validation cohort were generally lower than the derivation cohort, but are in keeping with other risk prediction models for older persons within the English secondary care administrative data(35, 41). There was marked variation in volume and frequency of coding for frailty syndromes across participating countries (Figure

2). These differences may reflect different coding practices and contrasting healthcare systems. These differences may contribute to poorer performance within the validation cohort. Nevertheless, within pooled data across all participating sites, the Dr Foster Global Frailty Score appears to significantly predict in-hospital mortality and upper quartile length of stay (for country) after multivariable adjustment for age, gender, country and co-morbidity.

When both the Elixhauser co-morbidity score and Dr Foster Global Frailty Score were included within multivariable adjustment, both scores remain statistically significant for the outcomes of in-hospital mortality and upper quartile length of stay, suggesting they are not collinear.

Although the setting for the validation cohort was sourced only from English data, it was a large dataset (N=~7m spells). After multivariable adjustment for age, gender and year, the Dr Foster Global Frailty Score remained significant for all three outcomes. Predictive power was demonstrated to be similar to a previous study(35), and comparable to the derivation cohort (Table 5).

In clinical practice, risk stratification in older persons for the secondary care setting often utilise demographics (including chronological age), physiological based track-and-trigger systems (e.g. National Early Warning Score(42)), biomarkers (e.g. troponin) and understanding about the prognosis of specific disease states(e.g. co-morbidity). When adjusting for case-mix between systems or at organisational level, registry(43) or administrative(28) data are often employed, as large scale high quality data from patient records are not readily available. Consequently, risk prediction models using administrative data have sought to differentiate risk by using diagnostic(27-30), procedural(31, 32) and more recently, prescribing codes(29, 33).

There are several risk models in the United States utilising frailty-specific groups of diagnostic codes within Medicare administrative data, Medicare Current Beneficiary Survey (MCBS) data and Veteran's Affairs (VA) administrative data. Examples of these risk prediction models include Johns Hopkins Adjusted Clinical Groups (ACG, Johns Hopkins University) frailty-defining diagnoses indicator(28) and High-Risk Diagnosis for the Elderly Scale(30). In the UK, studies exploring case-mix adjustment for older persons using administrative data have utilised HES as a data source, with diagnostic groups for multimorbidity(38) and complexity(44), as well as frailty(35, 41) being tested in the literature. Appendix 4 summarises the characteristics, setting, data sources, predictor and outcome variables and performance of recent case-mix studies for older persons utilising

administrative data. Where predictive capacity is known, the Dr Foster Global Frailty Score performs comparably if not favourably.

Our study benefits from being a large multicentre international study across Europe, Australia and the United States that utilised routinely collected administrative data with the aim of case-mix adjustment for older persons in secondary care. The datasets represent whole populations, and there was little missing data. Our study employed robust statistical methods and included validation of the Dr Foster Global Frailty Score on an external dataset. It expands the diagnostic coding, provides external validation for a previous UK study(35) and extends it to include elective patients. The approach of targeting frailty syndromes for hospitalised patients has support in existing literature(45), and in keeping with national standards bodies recommendations in the UK(34, 46, 47). Additionally, our model's predictive capacity is not improved on by a recent UK study(41), and its predictive capacity is arguably more uniform across the three outcomes. However, we note that our model's predictive powers are not suitable for clinical risk prediction at the patient's bedside (AUC >0.80). Further investigation of appropriate cut-points based on desired model sensitivity and specificity for the above outcomes depending on how the model is used (e.g. health resource planning) represents future work.

However, some limitations warrant mention. The variability in frequency of coding of frailty syndromes across countries may limit reliability and generalisability, although the country of origin was accounted for in the multivariable regression. Further subgroup analysis in countries with similar frequency of coding, or hierarchical regression to account for clusters, may be the next step. The hospitals that contributed data to the Global Comparators dataset were mainly large academic centres with reputations of clinical excellence. As such, the quality of coding and patient outcomes represented may not be representative of other institutions. The score was developed on hospitalised populations of age ≥ 75 years as the majority of frail older persons fall within this age-group, particularly in Western Europe. This score is therefore not validated in those who fall below 75 years of age. Additionally, the study focused on hospitalised patients of ≥24 hours to exclude patients admitted to observational units, for investigations or procedures. There is increasing acceptance for the acute medical management of older persons in an ambulatory setting. This methodology will exclude same-day discharges, limiting generalisability.

The accuracy of coding in administrative data has been challenged, and sampling of local clinical units was not feasible. The Dr Foster Global Frailty Score was based on diagnostic codes and thus did not fully encompass all dimensions of frailty such as functional and

socio-environmental measures as these are not well coded in the administrative data at this time. Future work linking the datasets to pharmacy, social care, primary care and registry data may provide for a richer comprehensive case-mix adjustment. A small proportion of the validation cohort may have been duplicated from the derivation cohort (eight hospitals in calendar year 2013). However, using national data from several calendar years minimises the effect of this overlap. Lastly, We have not demonstrated population segmentation utilising the Dr Foster Global Frailty Score to show separation of risk for the three outcomes above, and this represents future work.

Our study adds to the existing literature regarding the secondary use of administrative data for case-mix adjustment in general, and for hospitalised older persons in particular. It links the clinically valid concept of frailty syndromes to a reproducible method of measurement within administrative datasets. The Dr Foster Global Frailty Score may potentially be used to routinely identify older persons at risk of adverse outcomes for the purposes of targeted resource allocation, commissioning or service development. It may form the basis of a global comparator of risk adjustment for older persons.

Conclusion

Frailty Syndromes can be feasibly coded in international secondary care administrative datasets. The Dr Foster Global Frailty Score based on coded frailty syndromes significantly predicts in-hospital mortality and upper quartile length of stay in international datasets, and additionally 30-day non-elective readmission in England's national hospital dataset. This methodology may be feasibly utilised for case-mix adjustment for older persons across the international setting.

Figures Legend

Figure 1: Summary of 30 risk prediction models undertaken, accounting for admission status, frailty and co-morbidity

Figure 2: Example of 2-step multivariable logistic regression process for the outcome of upper quartile length of stay.

Figure 3a: Percentage Volume of patients aged ≥ 75 year to total volume by country and year within Global Comparators Dataset

Figure 3b: Frequency of coding for frailty syndromes by country for year 2013 within Global Comparators Dataset (colour scale by country) in patients aged ≥ 75 years

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Competing interest statement

CP has shares in Fidelity Health, has been a consultant for Merck and the Institute for Healthcare Improvement.

Ethics approval

Data sharing agreements with all individual hospitals included were in place in order to receive the data. The data used in this study was collected for administrative purposes and anonymized. As per Governance Arrangements for Research Ethics Committees (GAfREC), research limited to secondary use of information previously collected in the course of normal care (without an intention to use it for research at the time of collection), provided that the patients or service users are not identifiable to the research team in carrying out the research.

Authors contribution

JTYS conceived study, designed analysis, interpreted results and wrote first draft. AH conceived study, designed analysis, interpreted results. JK, DL, CP and CC designed analysis, interpreted results and contributed to ongoing writing. AB and DB interpreted results and contributed to ongoing writing.

Data Sharing

The data used for this study was available due to data sharing agreements signed with the individual hospitals as part of their participation in the Global Comparators programme managed by Dr Foster. The Global Comparators programme no longer exists and therefore data sharing agreements are no longer in place to allow for supplementary data sharing.

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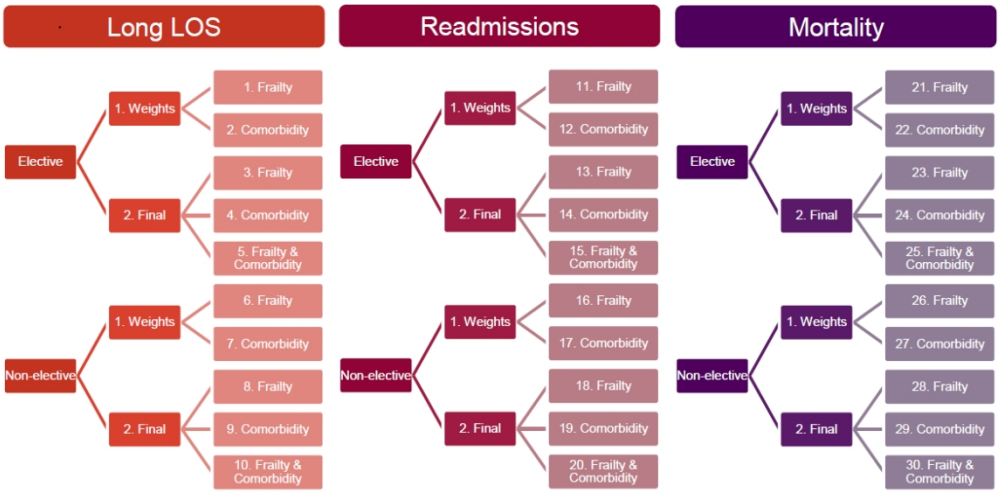

Figure 1: Summary of 30 risk prediction models undertaken, accounting for admission status, frailty and co-morbidity

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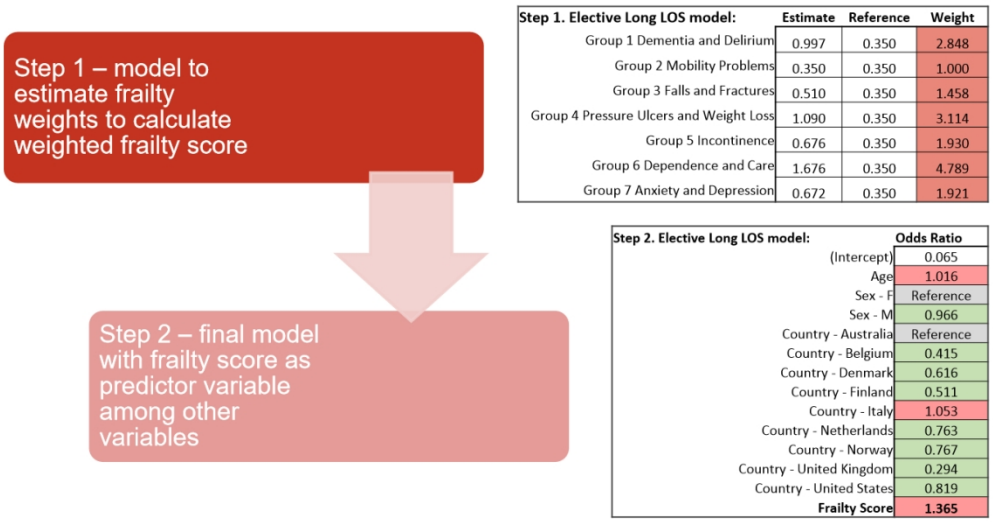

Step 1. Elective Long LOS model:	Estimate	Reference	Weight
Group 1 Dementia and Delirium	0.997	0.350	2.848
Group 2 Mobility Problems	0.350	0.350	1.000
Group 3 Falls and Fractures	0.510	0.350	1.458
Group 4 Pressure Ulcers and Weight Loss	1.090	0.350	3.114
Group 5 Incontinence	0.676	0.350	1.930
Group 6 Dependence and Care	1.676	0.350	4.789
Group 7 Anxiety and Depression	0.672	0.350	1.921

Step 2. Elective Long LOS model:	Odds Ratio
(Intercept)	0.065
Age	1.016
Sex - F	Reference
Sex - M	0.966
Country - Australia	Reference
Country - Belgium	0.415
Country - Denmark	0.616
Country - Finland	0.511
Country - Italy	1.053
Country - Netherlands	0.763
Country - Norway	0.767
Country - United Kingdom	0.294
Country - United States	0.819
Frailty Score	**1.365**

Figure 2: Example of 2-step multivariable logistic regression process for the outcome of upper quartile length of stay.

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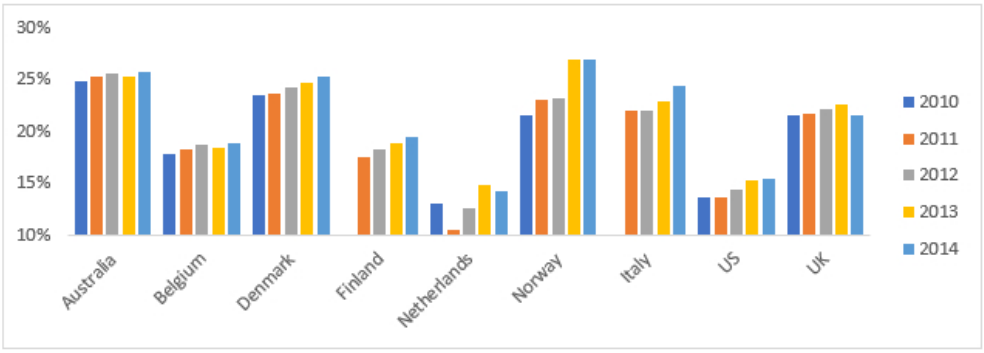

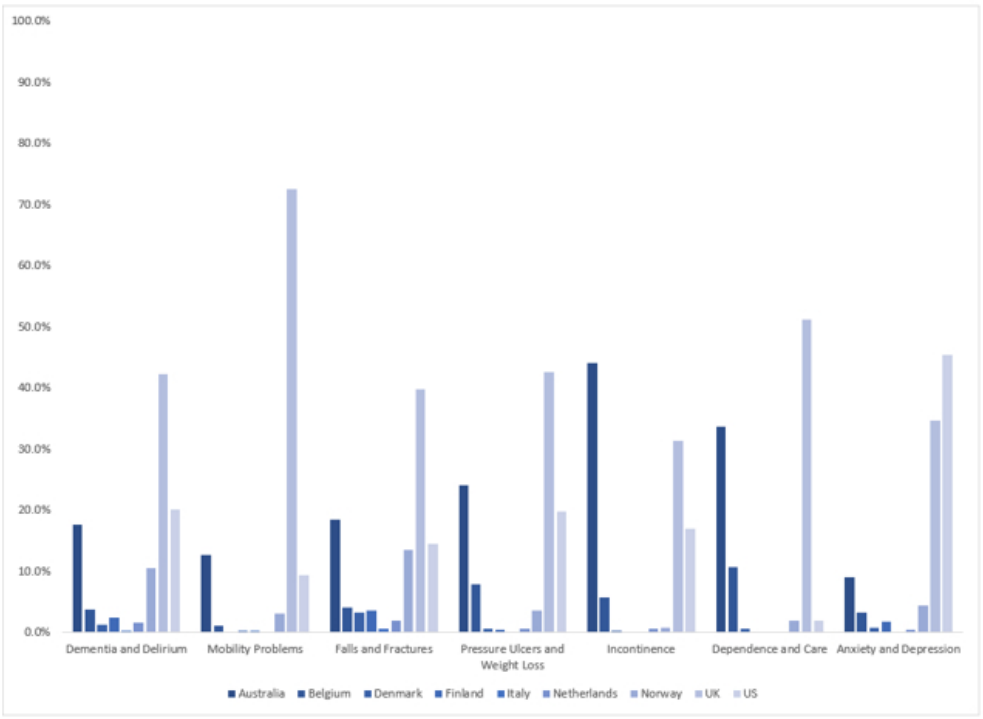

Figure 3a: Percentage Volume of patients aged ≥ 75 year to total volume by country and year within Global Comparators Dataset

Figure 3b: Frequency of coding for frailty syndromes by country for year 2013 within Global Comparators Dataset (colour scale by country) in patients aged ≥ 75 years

54x60mm (300 x 300 DPI)

Appendix 1 ICD-10 and ICD-9 coding for frailty syndromes

Group	ICD -10	Description (ICD-10)	ICD-9	Description (ICD-9)
1. Dementia and Delirium	F00	Dementia in Alzheimer's disease	2904	Arteriosclerotic dementia
	F01	Vascular dementia	2941-2942	Dementia in other diseases and unspecified dementia
	F02	Dementia in other diseases classified elsewhere	2930-2931	Subacute delirium and delirium due to conditions classified elsewhere
	F03	Unspecified dementia	V4031	Wandering in diseases classified elsewhere
	F05	Delirium not induced by alcohol and other psychoactive	3310	Alzheimer's disease
	G30	Alzheimer's disease	3312	Senile degeneration of brain
	G31 1	Senile degeneration of brain, not elsewhere classified	2900-2903	Senile and presenile dementia, dementia with delirium
	G31 0	Circumscribed brain atrophy	33119	Other frontotemporal dementia
	F04	Organic amnesic syndrome, not induced by alcohol and other psychoactive substances	33182	Dementia with lewy bodies
	R41	Other symptoms and signs involving cognitive functions and awareness	2908-2909	Other senile psychotic conditions
			2948-2949	Other persistent mental disorders due to conditions classified elsewhere
			2940	Amnestic disorder in conditions classified elsewhere
2. Mobility Problems	R26	Abnormalities of gait and mobility	7812	Abnormality of gait
	R29 8	Other and unspecified symptoms and signs involving the nervous and musculoskeletal systems	78199	Other symptoms involving nervous and musculoskeletal systems
3. Falls and Fractures	S32	Fracture of lumbar spine and pelvis	8054-8055	Fracture of lumbar vertebra without mention of spinal cord injury
	S33	Dislocation, sprain and strain of joints and ligaments of lumbar spine and pelvis	8064-8065	Fracture of lumbar spine with spinal cord injury
	S42	Fracture of shoulder and upper arm	8056-8057	Fracture of sacrum and coccyx without mention of spinal cord injury
	S43	Dislocation, sprain and strain of joints and ligaments of shoulder girdle	8066-8067	Fracture of sacrum & coccyx with spinal cord injury
	S52	Fracture of forearm	808-809	Fracture of pelvis and Ill-defined fractures of bones of trunk
	S53	Dislocation, sprain and strain of joints and ligaments of elbow	8392-8393	Dislocation, thoracic & lumbar vertebra
	S62	Fracture at wrist and hand level	83941 - 83952	Dislocation, coccyx and sacrum
	S63	Dislocation, sprain and strain of joints and ligaments at wrist and hand level	846	Sprains & strains of sacroiliac region
	S72	Fracture of femur	8472-8474	Sprain of lumbar, sacrum, coccyx
	S73	Dislocation, sprain and strain of joint and ligaments of hip	8485	Sprain of pelvic
	W0-W1	Falls	810-812	Fracture of clavicle, scapula, humerus
	M80	Osteoporosis with pathological fracture	831-835	Dislocation of shoulder, elbow, wrist, finger, hip
	M81	Osteoporosis without pathological fracture	840-843	Sprains & strains of shoulder, upper arm, elbow, forearm, wrist, hand, hip, thigh
	R296	Tendency to fall, not elsewhere classified	83961 & 83971	Dislocation, sternum
	R55	Syncope and collapse	8484	Sternum sprain
	R54	Senility	813-817	Fracture of radius & ulna, carpal bone(s), metacarpal bone(s), phalanges of hand
	M9 66	Fracture of bone following insertion of orthopaedic implant, joint prosthesis, or bone plate	820-821	Fracture of neck of femur and other parts of femur
			E88	Falls

			7330	Osteoporosis
			7331	Pathological fracture
			V1588	History of fall
			7802	Syncope and collapse
			797	Senility without mention of psychosis
			9964	Mechanical complication of internal orthopedic device implant and graft
4. Pressure Ulcers and Weight Loss	L89	Decubitus ulcer and pressure area	7072	Pressure ulcer
	R634	Abnormal weight loss	7070	Decubitus ulcer
	R636	Insufficient intake of food and water due to self neglect	7832	Abnormal Loss of Weight
	Z724	Inappropriate diet and eating habits	V691	Inappropriate diet and eating habits
5. Incontinence	R32	Unspecified urinary incontinence	7883	Incontinence of urine
	R15	Faecal incontinence	7876	Incontinence of feces
6. Dependence and Care	Z74	Problems related to care-provider dependency	V604	No other household member able to render care
	Z75	Problems related to medical facilities and other health care	V63	Unavailability of other medical facilities for care
7. Anxiety and Depression	F38	Other mood [affective] disorders	2969	Other & unspecified affective psychoses
	F41	Other anxiety disorders	3000	Anxiety states
	F43	Reaction to severe stress, and adjustment disorders	308	Acute reaction to stress
	F44	Dissociative [conversion] disorders	309	Adjustment reaction
	F064	Organic anxiety disorder	3001	Hysteria
	F32	Depressive episode	2962	Major depressive disorder, single episode
	F33	Recurrent depressive disorder	2963	Major depressive disorder, recurrent episode
	F204	Post-schizophrenic depression	2965	Bipolar affective disorder, depressed
	F251	Schizoaffective disorder, depressive type	3004	Dysthymic disorder
	F31	Bipolar affective disorder	3090	Adjustment disorder with depressed mood
	F341	Dysthymia	3091	Prolonged depressive reaction
	F412	Mixed anxiety and depressive disorder	3092	Adjustment reaction with predominant disturbance of other emotions
	F432	Adjustment disorders	2968	Manic-depressive psychosis, other & unspecified
			2980	Depressive type psychosis
			3011	Affective personality disorder
			311	Depressive disorder, not elsewhere classified

Appendix 2: Odds Ratios for Frailty Score after adjustment for age, gender, country for the outcomes of in-hospital mortality, 30-day non-elective readmission and upper quartile length of stay (for country), by elective and non-elective population groups within the Global Comparators Dataset (Derivation)

In-hospital mortality

Table 12: Odds Ratios of Frailty Score for in-hospital mortality adjusted for age, gender country within each subgroup (elective and non-elective)

Elective

	Odds Ratio	Lower CI	Upper CI	P-value
(Intercept)	0.001	0.000	0.001	<0.001
Age	1.041	1.029	1.054	<0.001
Sex - F	Reference			
Sex - M	1.441	1.277	1.626	<0.001
Country - Australia	Reference			
Country - Belgium	1.039	0.836	1.292	0.730
Country - Denmark	0.913	0.668	1.248	0.569
Country - Finland	0.318	0.227	0.446	<0.001
Country - Italy	0.702	0.496	0.994	0.046
Country - Netherlands	1.413	1.107	1.803	0.005
Country - Norway	0.616	0.492	0.770	<0.001
Country - United Kingdom	0.566	0.467	0.686	<0.001
Country - United States	0.838	0.686	1.023	0.082
Frailty Score	1.277	1.247	1.308	<0.001

Non-elective

	Odds Ratio	Lower CI	Upper CI	P-value
(Intercept)	0.002	0.002	0.003	<0.001
Age	1.040	1.037	1.043	<0.001
Sex - F	Reference			
Sex - M	1.305	1.265	1.346	<0.001
Country - Australia	Reference			
Country - Belgium	1.338	1.213	1.478	<0.001
Country - Denmark	1.480	1.371	1.598	<0.001
Country - Finland	0.936	0.864	1.015	0.109
Country - Italy	1.682	1.462	1.936	<0.001
Country - Netherlands	1.525	1.361	1.709	<0.001
Country - Norway	1.001	0.942	1.062	0.987
Country - United Kingdom	1.492	1.419	1.570	<0.001
Country - United States	0.897	0.844	0.953	<0.001
Frailty Score	1.109	1.103	1.116	<0.001

30-day non-elective readmission

Table 13: Odds Ratios of Frailty Score for 30-day non-elective readmission adjusted for age, gender country within each subgroup (elective and non-elective)

Elective

	Odds Ratio	Lower CI	Upper CI	P-value
(Intercept)	0.037	0.021	0.065	<0.001
Age	1.002	0.995	1.009	0.622
Sex - F	Reference			
Sex - M	1.159	1.087	1.236	<0.001
Country - Australia	Reference			
Country - Belgium	0.893	0.758	1.053	0.179
Country - Denmark	1.573	1.339	1.847	<0.001
Country - Finland	1.153	1.003	1.326	0.045
Country - Italy	0.500	0.391	0.640	<0.001
Country - Netherlands	1.174	0.988	1.395	0.068
Country - Norway	1.616	1.434	1.821	<0.001
Country - United Kingdom	1.094	0.975	1.228	0.125
Country - United States	1.323	1.168	1.498	<0.001
Admission History	1.453	1.411	1.495	<0.001
Frailty Score	1.106	1.060	1.154	<0.001

Non-elective

	Odds Ratio	Lower CI	Upper CI	P-value
(Intercept)	0.112	0.091	0.136	<0.001
Age	0.998	0.996	1.001	0.201
Sex - F	Reference			
Sex - M	1.167	1.137	1.198	<0.001
Country - Australia	Reference			
Country - Belgium	0.803	0.722	0.893	<0.001
Country - Denmark	1.317	1.231	1.408	<0.001
Country - Finland	0.995	0.931	1.063	0.879
Country - Italy	0.760	0.646	0.893	0.001
Country - Netherlands	0.774	0.683	0.877	<0.001
Country - Norway	1.582	1.507	1.660	<0.001
Country - United Kingdom	1.362	1.302	1.425	<0.001
Country - United States	1.274	1.211	1.340	<0.001
Admission History	1.315	1.303	1.326	<0.001
Frailty Score	1.056	1.031	1.082	<0.001

Upper Quartile Length of Stay (for country)

Table 14: Odds Ratios of Frailty Score for Upper Quartile Length of Stay (for country) adjusted for age, gender country within each subgroup (elective and non-elective)

Elective

	Odds Ratio	Lower CI	Upper CI	P-value
(Intercept)	0.065	0.045	0.094	<0.001
Age	1.016	1.011	1.020	<0.001
Sex - F	Reference			
Sex - M	0.966	0.927	1.008	0.112
Country - Australia	Reference			
Country - Belgium	0.415	0.376	0.457	<0.001
Country - Denmark	0.616	0.549	0.691	<0.001
Country - Finland	0.511	0.467	0.558	<0.001
Country - Italy	1.053	0.953	1.162	0.310
Country - Netherlands	0.763	0.691	0.843	<0.001
Country - Norway	0.767	0.713	0.825	<0.001
Country - United Kingdom	0.294	0.273	0.316	<0.001
Country - United States	0.819	0.765	0.878	<0.001
Frailty Score	1.365	1.347	1.382	<0.001

Non-elective

	Odds Ratio	Lower CI	Upper CI	P-value
(Intercept)	0.284	0.245	0.330	<0.001
Age	0.995	0.993	0.996	<0.001
Sex - F	Reference			<0.001
Sex - M	1.055	1.034	1.076	<0.001
Country - Australia	Reference			<0.001
Country - Belgium	1.766	1.658	1.881	<0.001
Country - Denmark	1.570	1.492	1.652	<0.001
Country - Finland	1.705	1.628	1.786	<0.001
Country - Italy	2.270	2.074	2.484	<0.001
Country - Netherlands	2.268	2.112	2.435	<0.001
Country - Norway	1.303	1.254	1.353	<0.001
Country - United Kingdom	1.508	1.459	1.559	<0.001
Country - United States	1.434	1.382	1.488	<0.001
Frailty Score	1.199	1.194	1.205	<0.001

Appendix 3: Odds Ratios for Frailty Score after adjustment for age, gender, calendar year for the outcomes of in-hospital mortality, 30-day non-elective readmission and upper quartile length of stay (for country), by elective and non-elective population groups in Hospital Episode Statistics dataset (Validation)

In-hospital mortality

Table 15: Odds Ratios of Frailty Score for in-hospital mortality adjusted for age, gender and calendar year within each subgroup (elective and non-elective)

Elective

	Odds Ratio	Lower CI	Upper CI	Z-value	P-value
(Intercept)	0.001	0.001	0.001	-338.153	0.000
Age	1.051	1.050	1.051	206.705	0.000
Sex - F	Reference				
Sex - M	1.274	1.267	1.281	84.839	0.000
Calendar Year - 2012	Reference				
Calendar Year - 2013	0.938	0.931	0.945	-16.172	0.000
Calendar Year – 2014	0.851	0.844	0.857	-40.603	0.000
Calendar Year – 2015	0.865	0.858	0.871	-36.727	0.000
Frailty Score	1.173	1.171	1.174	279.196	0.000

Non-elective

	Odds Ratio	Lower CI	Upper CI	Z-value	P-value
(Intercept)	0.001	0.001	0.001	-353.600	0.000
Age	1.055	1.055	1.056	227.822	0.000
Sex - F	Reference				
Sex - M	1.233	1.226	1.240	73.302	0.000
Calendar Year - 2012	Reference				
Calendar Year - 2013	0.936	0.929	0.944	-16.598	0.000
Calendar Year – 2014	0.850	0.844	0.857	-40.640	0.000
Calendar Year – 2015	0.869	0.862	0.876	-35.371	0.000
Frailty Score	1.108	1.107	1.109	315.847	0.000

30-day non-elective readmission

Table 16: Odds Ratios of Frailty Score for 30-day non-elective readmission adjusted for age, gender and calendar year within each subgroup (elective and non-elective)

Elective

	Odds Ratio	Lower CI	Upper CI	Z-value	P-value
(Intercept)	0.055	0.054	0.057	-186.458	0.000
Age	1.011	1.010	1.011	58.247	0.000
Sex - F	Reference				
Sex - M	1.119	1.114	1.123	53.787	0.000
Calendar Year - 2012	Reference				
Calendar Year - 2013	0.994	0.989	1	-1.918	0.055
Calendar Year – 2014	1.015	1.009	1.021	5.090	0.000
Calendar Year – 2015	1.018	1.012	1.024	6.228	0.000
Previous Emergency Admissions	1.443	1.440	1.445	379.358	0.000
Frailty Score	1.045	1.044	1.047	77.860	0.000

Non-elective

	Odds Ratio	Lower CI	Upper CI	Z-value	P-value
(Intercept)	0.053	0.051	0.054	-191.317	0.000
Age	1.011	1.011	1.012	62.570	0.000
Sex - F	Reference				
Sex - M	1.121	1.117	1.126	54.752	0.000
Calendar Year - 2012	Reference				
Calendar Year - 2013	0.993	0.987	0.998	-2.526	0.012
Calendar Year – 2014	1.012	1.007	1.018	4.231	0.000
Calendar Year – 2015	1.015	1.010	1.021	5.218	0.000
Previous Emergency Admissions	1.439	1.436	1.442	376.406	0.000
Frailty Score	1.030	1.030	1.031	85.172	0.000

Upper quartile length of stay

Table 17: Odds Ratios of Frailty Score for upper quartile length of stay adjusted for age, gender and calendar year within each subgroup (elective and non-elective)

Elective

	Odds Ratio	Lower CI	Upper CI	Z-value	P-value
(Intercept)	0.030	0.029	0.031	-258.331	0.000
Age	1.023	1.023	1.024	143.925	0.000
Sex - F	Reference				
Sex - M	0.940	0.937	0.944	-32.930	0.000
Calendar Year - 2012	Reference				
Calendar Year - 2013	0.975	0.970	0.980	-9.874	0.000
Calendar Year – 2014	0.891	0.886	0.895	-44.736	0.000
Calendar Year – 2015	0.872	0.868	0.877	-52.705	0.000
Frailty Score	1.193	1.192	1.193	593.715	0.000

Non-elective

	Odds Ratio	Lower CI	Upper CI	Z-value	P-value
(Intercept)	0.031	0.030	0.032	-255.862	0.000
Age	1.023	1.022	1.023	139.087	0.000
Sex - F	Reference				
Sex - M	0.948	0.944	0.951	-28.576	0.000
Calendar Year - 2012	Reference				
Calendar Year - 2013	0.979	0.974	0.984	-8.288	0.000
Calendar Year – 2014	0.896	0.891	0.900	-42.538	0.000
Calendar Year – 2015	0.878	0.874	0.883	-50.020	0.000
Frailty Score	1.055	1.055	1.055	602.049	0.000

Appendix 4 Case-mix adjustment for older persons utilising administrative data

Author	Year	Country	Study population	N	Data Source	Outcome	Predictors	Model performance
Von Korff et al.(1)	1991	United States	Population based pharmacy data	122911	Administrative	Mortality and hospitalisation	Consensus based Chronic Disease Score(CDS)	
Rosen et al.(2)	2001	United States	Long-term facility resident (Veterans Affairs)	39839	Administrative (Patient Assessment File(PAF), Patient Treatment File(PTF), Extended Care File(ECF))	Decline in functional status	International Classification of Diseases, Ninth Revision Clinical Modification (ICD-9) , demographics, treatments, activities of daily living	AUC for decline in functional status is 0.70
Desai et al.(3)	2002	United States	≥70 admitted to geriatric service	1376	Administrative (Management Information System)	Mortality	International Classification of Diseases system, version 9 (ICD-9)	AUC 0.76 for mortality in derivation and AUV 0.68 in validation)
Kautter et al(4)	2004	United States	Medicare	17597	Administrative The Medicare Current Beneficiary Survey (MCBS)	Cost	ADLs, Long-term institution status, Age	
Roland et al.(5)	2005	United Kingdom	Individual patients aged ≥ 65, ≥ 75, and ≥ 85who had at least two emergency admissions	227206	Administrative (Hospital Episode Statistics)	Non-elective hospital readmission	Individual patients aged ≥ 65who had at least two emergency admissions	

Inoye et al.(6)	2008	United States	Primary care clinic	3919	Administrative	Non-elective hospital admission	Deyo-Charlson comorbidity score ≥ 4, any prior hospitalization, 6 or more primary care visits, ≥ 85 years unmarried status	AUC 0.73
Sternberg et al.(7)	2012	Israel	Patients receiving Comprehensive Geriatric Assessment via OPD	221	Administrative; and survey	Resource utilisation (number of physician visits in 3 months, number of ED visits in a year, and number of hospitalizations in the year)	VES Frailty Score(13-item function-based self-report questionnaire Adjusted Clinical Groups diagnoses based predictive model (ACG Dx-PM) based on age, sex, diagnostic codes, and pharmacy data	ACG predict frailty defined by VES – AUC 0.63
Davidoff et al.(8)	2013	United States	US Medicare beneficiaries aged ≥ 65 years	14788	Administrative (Medicare) and Medicare Current Beneficiary Survey (MCBS),	Disability Status	Healthcare services, Berenson-Eggers Type of Service (BETOS) codes, American Medical Association's Current Procedural Terminology (CPT) codes, or the ICMS, Healthcare Common Procedure Coding System (HCPCS level II) codes, demographic	AUC 0.92 for disability status
Bottle et al.(9)	2014	United Kingdom	Admitted with heart failure	84212	Administrative (Hospital Episode statistics)	Non-elective hospital readmission	AHRQ's (Agency for Healthcare Research and Quality) Clinical Classification System International Classification of Diseases system version 10 (ICD-10)	
Chrischilles et al.(10)	2014	United States	US Medicare beneficiaries aged ≥ 65 years admitted with acute	144112	Administrative	Mortality, cardiac catheterisation	Demographic measures, cardiovascular conditions, comorbidities, previous hospitalization, and Function related indicators(FRI)	AUC Mortality 0.74, AUC cardiac catheterisation 0.79, Including the FRIs improved

			myocardial infarction					prediction models
Ruiz et al.(11)	2015	United Kingdom	Individual patients aged ≥ 65 with hospital admission	2788900	Administrative (Hospital Episode Statistics)	Mortality, Non-elective hospital readmission, Hospital admission	≥ 65 years old who have at least 3 simultaneous diagnoses of major clinical conditions.	
Faurot et al.(12)	2015	United States	≥ 65 community dwelling	6391	Administrative and Medicare Current Beneficiary Survey (MCBS)	Functional decline	demographics, International Classification of Diseases, Ninth Revision Clinical Modification (ICD-9) diagnosis/procedure and durable medical equipment codes for frailty-associated conditions, (Current Procedural Terminology (CPT) and Healthcare Common Procedure Coding System (HCPC))	
Hope et al.(13)	2015	United States	>70 admitted to ICU	47427	Administrative (Medicare)	Mortality	International Classification of Diseases, Ninth Revision Clinical Modification (ICD-9) diagnosis & claims for skilled nursing facility: creation of four categories: 1)Cancer 2)Chronic Organ Failure3)Frailty4) Robust	
Soong et al.	2015	United Kingdom	>65 non-elective admission to hospital	2 099 252	Administrative	Mortality, non-elective readmission, functional decline	ICD-10 codes, Frailty Syndromes	AUC of 0.624–0.659 for inpatient mortality, 0.63–0.654 for institutionalisation and 0.57–0.63 for 30-day

								emergency readmission.
Briggs et al.(14)	2016	Ireland	Patients admitted with dementia to single hospital	929	Administrative	Cost	International Classification of Diseases system version 10 (ICD-10)	
McIsaac et al.(15)	2016	Canada	>65 years Elective non-cardiac surgery	202811	Administrative Discharge Abstract Database, Ontario Health Insurance Plan Database, Registered Persons Database	Inpatient mortality	John's Hopkins Adjusted Clinical Groups (ACG, Johns Hopkins University) frailty-defining diagnoses indicator,	
Kim et al.(16)	2017	United States	≥ 65 community dwelling	10017	Administrative (Medicare) and Medicare Current Beneficiary Survey (MCBS)	Mortality, disability, mobility impairment, and recurrent falls	International Classification of Diseases, Ninth Revision Clinical Modification (ICD-9) (Current Procedural Terminology (CPT) and Healthcare Common Procedure Coding System (HCPC)) to create a frailty index	
Gilbert et al.(17)	2018	United Kingdom	>75 years elective and non-elective admissions to hospital	1 013 590	Administrative Hospital Episode Statistics	Mortality, long length of stay, non-elective readmission	ICD-10 Codes identified by cluster analysis for Bed days, Hospital costs, and ICD-10 coded Frailty Syndromes	AUC 0·60 for 30-day mortality, 0·68 for long hospital stay, 0·56 for 30-day readmission.

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TRIPOD Checklist: Prediction Model Development and Validation

Section/Topic	Item		Checklist Item	Page
Title and abstract				
Title	1	D;V	Identify the study as developing and/or validating a multivariable prediction model, the target population, and the outcome to be predicted.	2
Abstract	2	D;V	Provide a summary of objectives, study design, setting, participants, sample size, predictors, outcome, statistical analysis, results, and conclusions.	3
Introduction				
Background and objectives	3a	D;V	Explain the medical context (including whether diagnostic or prognostic) and rationale for developing or validating the multivariable prediction model, including references to existing models.	5
	3b	D;V	Specify the objectives, including whether the study describes the development or validation of the model or both.	5
Methods				
Source of data	4a	D;V	Describe the study design or source of data (e.g., randomized trial, cohort, or registry data), separately for the development and validation data sets, if applicable.	6
	4b	D;V	Specify the key study dates, including start of accrual; end of accrual; and, if applicable, end of follow-up.	6-7
Participants	5a	D;V	Specify key elements of the study setting (e.g., primary care, secondary care, general population) including number and location of centres.	7
	5b	D;V	Describe eligibility criteria for participants.	7
	5c	D;V	Give details of treatments received, if relevant.	NA
Outcome	6a	D;V	Clearly define the outcome that is predicted by the prediction model, including how and when assessed.	9
	6b	D;V	Report any actions to blind assessment of the outcome to be predicted.	NA
Predictors	7a	D;V	Clearly define all predictors used in developing or validating the multivariable prediction model, including how and when they were measured.	8-9, App 1
	7b	D;V	Report any actions to blind assessment of predictors for the outcome and other predictors.	NA
Sample size	8	D;V	Explain how the study size was arrived at.	7
Missing data	9	D;V	Describe how missing data were handled (e.g., complete-case analysis, single imputation, multiple imputation) with details of any imputation method.	7
Statistical analysis methods	10a	D	Describe how predictors were handled in the analyses.	8-10
	10b	D	Specify type of model, all model-building procedures (including any predictor selection), and method for internal validation.	8-10
	10c	V	For validation, describe how the predictions were calculated.	8-10
	10d	D;V	Specify all measures used to assess model performance and, if relevant, to compare multiple models.	10
	10e	V	Describe any model updating (e.g., recalibration) arising from the validation, if done.	NA
Risk groups	11	D;V	Provide details on how risk groups were created, if done.	NA
Development vs. validation	12	V	For validation, identify any differences from the development data in setting, eligibility criteria, outcome, and predictors.	6-7
Results				
Participants	13a	D;V	Describe the flow of participants through the study, including the number of participants with and without the outcome and, if applicable, a summary of the follow-up time. A diagram may be helpful.	11, 15
	13b	D;V	Describe the characteristics of the participants (basic demographics, clinical features, available predictors), including the number of participants with missing data for predictors and outcome.	11
	13c	V	For validation, show a comparison with the development data of the distribution of important variables (demographics, predictors and outcome).	15-16
Model development	14a	D	Specify the number of participants and outcome events in each analysis.	11-14 App 2-3
	14b	D	If done, report the unadjusted association between each candidate predictor and outcome.	NA
Model specification	15a	D	Present the full prediction model to allow predictions for individuals (i.e., all regression coefficients, and model intercept or baseline survival at a given time point).	11-14 App 2-3
	15b	D	Explain how to the use the prediction model.	NA
Model performance	16	D;V	Report performance measures (with CIs) for the prediction model.	15-16
Model-updating	17	V	If done, report the results from any model updating (i.e., model specification, model performance).	NA
Discussion				
Limitations	18	D;V	Discuss any limitations of the study (such as nonrepresentative sample, few events per predictor, missing data).	18
Interpretation	19a	V	For validation, discuss the results with reference to performance in the development data, and any other validation data.	16-17
	19b	D;V	Give an overall interpretation of the results, considering objectives, limitations, results from similar studies, and other relevant evidence.	16-18 App 4
Implications	20	D;V	Discuss the potential clinical use of the model and implications for future research.	18-19
Other information				
Supplementary information	21	D;V	Provide information about the availability of supplementary resources, such as study protocol, Web calculator, and data sets.	App 1-4
Funding	22	D;V	Give the source of funding and the role of the funders for the present study.	19

TRIPOD Checklist: Prediction Model Development and Validation

*Items relevant only to the development of a prediction model are denoted by D, items relating solely to a validation of a prediction model are denoted by V, and items relating to both are denoted D;V. We recommend using the TRIPOD Checklist in conjunction with the TRIPOD Explanation and Elaboration document.