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Developing and validating a risk prediction model for acute care based on frailty syndromes

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Title: Developing and validating a risk prediction model for acute care based on frailty syndromes

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ABSTRACT:

Objectives: Population ageing may result in increased co-morbidity, functional dependence and poor quality of life. Mechanisms and pathophysiology underlying frailty have not been fully elucidated, thus absolute consensus on an operational definition for frailty is lacking. Frailty scores in the acute medical care setting have poor predictive power for clinically relevant outcomes. We explore the utility of frailty syndromes (as recommended by national guidelines) as a risk prediction model for the elderly in the acute care setting

Setting: English Secondary Care emergency admissions to NHS acute providers

Participants: There were N=2099252 patients over 65 years with emergency admission to NHS acute providers from 01/01/2012 to 31/12/2012 included in the analysis.

Primary and secondary outcome measures: Outcomes investigated include inpatient mortality, 30Day emergency readmission and institutionalisation. We used pseudorandom numbers to split patients into train (60%) and test (40%). Receiver Operator Characteristics Curves (ROC) and ordering the patients by deciles of predicted risk was used to assess model performance.

Using English Hospital Episode Statistics (HES) data, we built multivariable logistic regression models with independent variables based on frailty syndromes (ICD-10 coding), demographics and previous hospital utilization. Patients included were those >65yrs with emergency admission to acute provider in England (2012).

Results: Frailty syndrome models exhibited ROC scores of 0.624 – 0.659 for inpatient mortality, 0.63 – 0.654 for institutionalisation and 0.57-0.63 for 30 Day emergency readmission.

Conclusion: Frailty Syndromes are a valid predictor of outcomes relevant to acute care. The models predictive power is in keeping with other scores in the literature, but is a simple, clinically relevant and potentially more acceptable measurement for use in the acute care setting. Predictive powers of the score are not sufficient for clinical use

Key Words: Frailty Syndromes, risk prediction, acute, outcomes, model

Article Summary

- Frailty scores in the acute medical care setting have poor predictive power for clinically relevant outcomes. We explore the utility of frailty syndromes (as recommended by national guidelines) as a risk prediction model for the elderly in the acute care setting
- The model was developed on routinely collected whole population English administrative data (HES) - all spells for patients over 65 years with emergency admission to NHS acute providers from 01/01/2012 to 31/12/2012(N=2099252).
- Frailty syndrome models exhibited ROC scores of 0.624 – 0.659 for inpatient mortality, 0.63 – 0.654 for institutionalisation and 0.57-0.63 for 30 Day emergency readmission.
- Frailty Syndromes are a valid predictor of outcomes relevant to acute care. The models predictive power is in keeping with other scores in the literature. However, predictive powers of the score are not sufficient for clinical use.

Strengths and limitations of this study

- It is a simple clinical model that has moderate predictive powers outcomes relevant to acute medical care. It has reduced data requirements compared to existing frailty models trialled in the acute care setting with predictive powers evenly spread over three outcomes
- It is a model designed to be that could be applied at point of access to acute care, does not rely on self reported data and was derived from whole population data that is routinely collected
- This study adds to emerging knowledge surrounding the secondary use of administrative data. It provides a novel methodology to best utilize routinely collected data in a systematic and robust manner that minimizes limitations and optimizes data quality and reliability.
- HES is retrospectively coded, thus reflects the patient's condition at discharge from hospital.
- Diagnostic coding accuracy in HES has been challenged.

Title: Developing and validating a risk prediction model for acute care based on frailty syndromes

Introduction

In the majority of countries the population is living to a greater age. For some, this is associated with an increase in co-morbidity(1), functional dependence(2) and poorer quality of life(3), with a consequent higher health and social care cost. A large component of this increased need is reflected in hospital demand both for elective and non-elective care. Patients over the age of 65 constitute two thirds of admissions, 40% of all hospital bed days and 65% of NHS spend in acute care(4). Within this population there is group of patients that most clinicians and the public would regard or recognise as frail.

Much research has taken place in understanding the pathophysiology and mechanisms underlying frailty(5, 6), however assessing frailty reliably remains problematic and remains a research priority (7-13). This is compounded at present by the absence of consensus on an operational definition of frailty (14-16). Two broad approaches are described; a specific biophysical phenotype and an index of accumulated deficit model(17). Developing a reliable and practical method to quantify frailty and link to outcomes would help in clinical practice as well as provide a method for longitudinal population analysis. To date, published scores based on these operational definitions demonstrate only poor to moderate predictive powers within the acute medical care setting(9). A sensitive, clinically relevant and acceptable model is a pressing necessity.

Within elderly care there are a number of syndromes that are recognised the so-called "Giants of geriatrics" or frailty syndromes. These are common clinical presentations of multi-factorial ill-defined processes recognized in the elderly(18). They include cognitive impairment, pressure ulcers, mobility problems, falls and incontinence. Conceptually, they represent a final common pathway of concentric, non-linear processes formed by the interaction between aetiological and physiological mechanisms, as yet not fully elucidated(5). When complex systems fail, high-order systems tend to break down first(19). This potentially makes frailty syndromes a robust marker for this vulnerable patient cohort. In the acute care setting, they are associated with increased functional dependence and length of hospital stay(20). Current National guidelines for the care of the older person in acute care recommend using frailty syndromes as a possible methodology to assess for frailty(11, 12).

This study explores the hypothesis that frailty syndromes are a valid measure of frailty in the acute care population in England using routinely available secondary care data based on Hospital Episode Statistics (HES)(21). We aim to develop and validate a model of frailty based on these syndromes as the first steps of developing a sensitive clinically relevant assessment tool to be used at point of access of acute care. We aim to evaluate its predictive power for clinical outcomes relevant to acute medical care. For construct validity(22), we explore its association with the Charlson co-morbidity Score(23).

Methods

Data Source

The risk prediction model scope included all spells for patients over 65 years with emergency admission to NHS acute providers from 01/01/2012 to 31/12/2012(N=2099252). HES contain 20 fields per record for diagnoses codes that are defined in the tenth revision of the International Statistical Classification of Diseases, Injuries and Causes of Death (ICD-10). We systematically explored HES for ICD-10 diagnostic codes to group together for frailty syndromes (Appendix 1) in all 20 fields. To explore coding reliability and shifts, annual trend profiles for the grouped ICD-10 diagnostic codes in English HES data from January 2005 to March 2013. (Appendix 2). As a result of this analysis, English data from 2010-2012 was selected and we merged ICD-10 diagnostic codes for dementia, delirium and senility to form a unified frailty syndrome (cognitive impairment).

Model input and output variables

Each record in HES corresponds to a finished consultant episode, during which a patient is under the care of an individual consultant. These episodes were aggregated into hospital spells covering a patient's total length of stay in a hospital using established methodology(24). Emergency admissions were defined as those for which the method of admission was recorded as 'Emergency', either via accident and emergency services, a general practitioner, a Bed Bureau, a consultant outpatient clinic or other means (*admimeth*=21, 22, 23, 24, 28). Table 1 describes predictor variables for study, including patient demographics, frailty syndromes and previous service use. Table 2 describes output variables for investigation, including inpatient mortality, 30-Day emergency readmission and drop in functional dependence at discharge

Table 1 Predictor inputs for frailty risk prediction model (independent variables)

Name	Time Span	Description	Comments
Age	Current Spell	The startage field from HES	
Sex	Current Spell	The sex field from HES	
Admission Source	Current Spell	The admiSorc field from HES	
Charlson (Historic)	24 Month Historic Average	Calculated per spell, using all diagnoses from all episodes and then averaged. Excludes the current spell	
Charlson (Current)	Current Spell	Calculated using diagnoses in positions 2-20 from all episodes in the spell	
Anxiety & Depression	24 Month Historic Binary Indicator	A binary flag indicating whether a relevant diagnosis has been received during any inpatient spell in the past 24 months	Senility, Dementia and Delirium merged to form the Cognitive Impairment indicator because of changes in coding over time
Cognitive Impairment			
Dependence			
Falls & Fracture			
Incontinence			
Mobility Problems			
Pressure Ulcers			
No. of Emergency Admissions	12 Month Historic Count	The number of emergency admission spells in the previous 12 months, excluding the current spell	Normalised
Days since Last Emergency Admission	24 Month Historic	The number of days since the patient's last discharge from an emergency admission	Normalised. Default value used when the patient hasn't had an emergency admission in the previous 24 months

Table 2 Predictor outputs of frailty risk prediction model (dependant variables)

Name	Time Span	Description	Comments
Inpatient Mortality	Current Spell	Indicates if the discharge destination was death	
30 Day Emergency Readmission	30 days from discharge	Indicates if the patient had an emergency admission within 30 days of discharge from the current spell	
Increase in Functional Dependence	Current Spell	Binary outcome-indicates if the patient's discharge destination was associated with a higher level of functional dependence than the admission source	See functional dependence tiers below

Tier	Values In Tier
1	• The usual place of residence, including no fixed abode • Temporary place of residence when usually resident elsewhere, for example, hotels and residential educational establishments
2	• Local authority Part 3 residential accommodation: where care is provided • Non-NHS (other than Local Authority) run residential care home
3	• NHS run nursing home, residential care home or group home • Non-NHS (other than Local Authority) run nursing home
4	• NHS other hospital provider: ward for general patients or the younger physically disabled or A&E department • Non-NHS run hospital
5	• Non-NHS (other than Local Authority) run hospice

The model consisted of both historical and within-spell (2012) variables. Historical(2010-2012) diagnostic codes were chosen over in-spell ones when coding for frailty syndromes as this more accurately described a risk prediction model at the point of access to acute care. Charlson co-morbidity scores were calculated in HES using previously described methodology(25), using weightings originally described by Charlson (23).

Spells ending with inpatient mortality were excluded when predicting institutionalisation or readmission within 30 days. Spells where the admission source or discharge destination could not be allocated a tier were also excluded when calculating functional dependence (approximately <1% of spells not ending in mortality).

Model development and testing

Pseudorandom numbers split patients into train (60%) and test (40%) groups. We then split spells into train (1,259,185 spells) and test (840,067 spells) sets based upon the groupings (to ensure no patient appears in both train and test sets). This technique was further used to split the train group into 5 cross validation folds during model and hyper-parameter selection. Multi-collinearity between predictor variables was investigated by Variance Inflation Factor (VIF), where VIF scores of over 3 were taken to denote unacceptable collinearity. Scikit-learn(26) implementation of logistic regression with l2 regularisation was used to create the risk prediction model with Receiver Operator Characteristic(ROC) curves being produced from the predicted probabilities. For the final evaluation, each logistic regression model was trained on the entirety of the train set. The model co-efficients selected in the train set were then used to score all samples in the test set. Finally, ROC curves and AUC scores(27) were generated based upon the test set scores. Hosmer-Lemeshow(28) tests with scipy implementation of Pearson's chi-squared test were performed for goodness-of-fit. Ordering the patients by deciles of predicted risk allows a visual representation of the models discrimination.

Results

Mortality

None of the models predictor variables (patient demographics, frailty syndromes, previous service use) demonstrated unacceptable collinearity (1.1-2.8)[TABLE 3]. Table 4 describes the predictive power of various frailty syndromes models for within spell in-patient mortality (range of AUCs 0.624 – 0.659). The frailty syndromes & admission history model demonstrates moderate discriminatory power, with the top 10% of patients identified at highest risk of inpatient mortality having a mortality rate (13%) nearly twice the average population (7%)[FIGURE 1]. The addition of Charlson Co-morbidity Score did not significantly improve the predictive power of the model (AUC 0.641). However, in-spell Charlson and Frailty Syndrome models described slightly improved predictive power over historical models (Table 4 and 5).

Table 3 Variance inflation factor scores for predictor variables

Variance Inflation Factor Scores	
Age	2.6
Sex	1.8
Historic Charlson	1.1
Anxiety & Depression	1.7
Cognitive Impairment	1.1
Dependence	1.6
Fall	1.1
Incontinence	1.2
Mobility	1.1
Pressure Ulcers	1.8

Table 4 Frailty syndrome models to predict within spell in-patient mortality

Model	Odds Ratios		AUC
Historical Frailty Syndromes Model	Age	1.05	0.624
	Sex	1.30	
	Anxiety & Depression	0.94	
	Cognitive Impairment	1.21	
	Functional Dependence	1.11	
	Falls & Fracture	0.94	
	Incontinence	1.06	
	Mobility Problems	1.08	
	Pressure Ulcers	1.29	
In-Spell Frailty Syndromes Model	Age	1.05	0.659
	Sex	1.20	
	Anxiety & Depression	0.93	
	Cognitive Impairment	1.40	
	Functional Dependence	0.64	
	Falls & fracture	0.65	
	Incontinence	1.34	
	Mobility Problems	1.16	
	Pressure Ulcers	4.04	

Model	Odds Ratios		AUC
Historical Frailty Syndromes & Charlson Co-morbidity Scores	Age	1.05	0.641
	Sex	1.09	
	Charlson	1.20	
	Anxiety & Depression	0.98	
	Cognitive Impairment	1.01	
	Functional Dependence	1.02	
	Falls & Fracture	0.97	
	Incontinence	1.01	
	Mobility Problems	1.01	
	Pressure Ulcers	1.05	
Historical Frailty Syndromes & Admission History (final model)	Age	1.05	0.632
	Sex	1.21	
	Anxiety & Depression	0.95	
	Cognitive Impairment	1.05	
	Functional Dependence	1.04	
	Falls & fracture	0.90	
	Incontinence	1.02	
	Mobility Problems	1.02	
	Pressure Ulcers	1.11	
	No of Emergency admissions (12m)	0.97	
	Days since last Emergency Admission	0.79	

Table 5 Charlson co-morbidity models to predict within spell in-patient mortality

Model	Odds Ratios		AUC
Historic Charlson	Age	1.05	0.639
	Sex	1.31	
	Charlson	1.20	
In-Spell Charlson	Age	1.05	0.681
	Sex	1.02	
	Charlson	1.29	

Discharge to a higher level of support

Table 6 describes the predictive power of frailty syndrome models to predict discharge to a higher level of support (institutionalization) (range of AUCs 0.63 – 0.654). The frailty syndromes and admission source model demonstrated moderate discriminatory power, with the top 10% of patients identified at highest risk of being discharged to a higher level of support (17%) at nearly twice the average population(9%)[FIGURE 2]. Historic Charlson co-morbidity scores (taking into account age and gender) exhibited AUCs of 0.617.

Table 6 Frailty syndrome models to predict discharge with a higher level of support (institutionalization)

Model	Odds Ratios		AUC
Historic Frailty Syndromes & Admission History	Age	1.04	0.634
	Sex	0.94	
	Anxiety & Depression	0.98	
	Cognitive Impairment	1.36	
	Functional Dependence	1.20	
	Falls & Fracture	1.15	
	Incontinence	1.09	
	Mobility Problems	1.12	
	Pressure Ulcers	1.20	
	No of Emergency Admissions (last 12m)	0.82	
	Days since last Emergency Admission	0.98	
Historic Frailty Syndromes & Admission Source	Age	1.04	0.654
	Sex	0.94	
	Admission Source (x5)	0.42-2.60	
	Anxiety & Depression	0.94	
	Cognitive Impairment	1.36	
	Functional Dependence	1.17	
	Falls & Fracture	1.14	
	Incontinence	1.08	
	Mobility Problems	1.16	
	Pressure Ulcers	1.17	

Model	Odds Ratios		AUC
Historic Frailty Syndromes	Age	1.05	0.63
	Sex	0.95	
	Anxiety & Depression	1.02	
	Cognitive Impairment	1.24	
	Functional Dependence	1.05	
	Falls & Fracture	1.18	
	Incontinence	1.04	
	Mobility Problems	1.09	
	Pressure Ulcers	1.04	

30 Day Emergency readmission

Table 7 describes the predictive power of the frailty models to predict emergency readmission within 30 days (range of AUCs 0.57-0.63). The frailty syndromes and admission history model demonstrated moderate discriminatory power, with the top 10% of patients identified at highest risk of emergency readmission within 30 days (39%) at nearly twice the average population (21%)[FIGURE 3]. Historic Charlson co-morbidity scores (taking into account age and gender) exhibited AUCs of 0.591.

Table 7 Frailty syndrome models to predict emergency readmission within 30 days

Model	Odds Ratios		AUC
Historic Frailty syndromes	Age	1.00	0.574
	Sex	1.20	
	Anxiety & Depression	1.55	
	Cognitive Impairment	1.24	
	Functional Dependence	1.11	
	Falls & Fracture	1.25	
	Incontinence	1.11	
	Mobility	1.35	
	Pressure Ulcers	1.15	

Model	Odds Ratios		AUC
Historic Frailty Syndromes & Admission History	Age	1.00	0.630
	Sex	1.12	
	Anxiety & Depression	1.08	
	Cognitive Impairment	1.05	
	Functional Dependence	1.02	
	Falls & Fracture	1.03	
	Incontinence	1.02	
	Mobility	1.06	
	Pressure Ulcers	1.02	
	No of Emergency Admissions (last 12m)	1.47	
	Days since last Emergency Admission	0.67	

Discussion

Reliable recognition of frailty is a research and clinical priority for acute hospital care (7-13). It is essential to help inform routine clinical decision making and plan appropriate care. To date, there is no routinely available and reliable clinical score for use within the acute care setting. This study explores the use of internationally recognised frailty syndromes coded within HES data to potentially aid more reliable frailty recognition within the hospital setting. HES data can reliably provide data related to mortality, functional dependence (e.g. disability or institutionalization) and high resource need (e.g. occupied bed days or readmission).The ideal frailty assessment for acute care needs to be comprehensively multidimensional to avoid missing aspects of patient care that may contribute to further decline or harm. It needs to predict outcomes that are relevant to the patient, carers and to acute care providers. To be fit for purpose, it should be optimized for clinical usability: i.e. simple, reliable, does not fully rely on self or carer reported data and possess high sensitivity if functioning as a screening tool. Ideally, there should be the ability to personalize the assessment and "threshold" set to patient preference and previous level of functioning. It should be provide a method to measure frailty over the course of an episode of acute illness and over a patient's life as opposed to single isolated static measures. Ultimately, it should be able to highlight areas for intervention to prevent, reverse or minimize further decline.

Studies exploring the predictive power of frailty scales for outcomes relevant to the UK acute medical care setting [TABLE 8] include prospective observational cohort studies(8, 9, 29) and secondary analysis of routinely collected large datasets, both clinical(30) and administrative(25, 31). Our model performs uniformly across the clinical outcomes and is comparable in predictive power to frailty scores in the same setting. None of the models have predictive powers suitable for clinical risk prediction at the patient's bedside (AUC > 0.80). The exception to this is a single study in the AMU setting in rural Ireland(32), which reported AUCs of >0.8 for 30 day mortality and functional decline but the results of this secondary analysis of a clinical database was not reproduced in prospective observational study at a large teaching centre in the UK(10).

Table 8 Summary of the predictive power of frailty scores in acute care

Model/Scores	Mortality		Re-admission		Functional dependence	
	Inpatient	90 Day	30 Day	90 Day	Institutiona-lisation	≤ 2 points Barthel ADL
AUCs						
Charlson score 2012 (Historic)	0.64		0.59		0.62	
CHS model		0.61		0.52	0.57	0.55
SOF model		0.59		0.53	0.44	0.56
Avila-Funes		0.68		0.55	0.50	0.59
Rothman		0.67		0.53	0.45	0.59
Frailty Index		0.69		0.57	0.55	0.57
ISAR		0.62		0.60	0.65	0.60
PARR30			0.70			
RIGAMA	0.78		0.55		0.50	
Frailty Syndrome Models						
Frailty syndromes and admission source					**0.65**	
Frailty syndromes	**0.62**		**0.57**		**0.63**	
Frailty syndromes and admission history	**0.63**		**0.63**		**0.63**	

Our model has notable strengths. It is a simple clinical model that has moderate predictive powers outcomes relevant to acute medical care. It has less data requirements compared to the Frailty Index(36 input variables)(9), Patient At Risk of Readmission 30-Day(PARR30)(up to 18 input variables)(31), Risk Index for Geriatric Acute Medical Admissions(RIGAMA)(30 inout variables)(30) and Charlson Co-morbidity score(17 input variables)(25). Importantly in comparison to other scores, its predictive power appears to be evenly spread over the three outcomes and does not rely on self-reported data (e.g. Identifying Seniors at Risk (ISAR) score)(33) . It is a model designed to be that could be applied at point of access to acute care. It was derived from whole population data that is routinely collected, with applicability at population and patient level. This study adds to emerging knowledge surrounding the secondary use of administrative data. It provides a novel methodology to best utilize routinely collected data in a systematic and robust manner that minimizes limitations and optimizes data quality and reliability.

Existing frailty scores in the acute care setting have very different input variables (thus likely do not measure the same thing). Optimal outcome variable selection is also yet unclear. For example, our model and most existing frailty scores do not take into account illness severity or disease acuity. We postulate that the addition of variables included in the NEWS(34) score may improve discrimination of frailty models. RIGAMAs (30)notable predictive powers for inpatient mortality may reflect discrimination for acute critical illness given input variables that largely record physiological and metabolic derangement, including prognostic biomarkers (e.g. Troponin). However, it may be that the optimal outcome variable for frailty in acute care is 30-day or 90-day mortality.

Studies of frailty scales in the Emergency Department setting display similar predictive powers for a wide-range of outcomes: *HK-ISAR* >65 years discharged from ED AUC 0.59-0.62 for composite outcome of institutionalisation, re-attendance or death(35); *ISAR* score > 65 years admitted to hospital via ED AUC 0.549-0.584(36), AUC 0.66 for depressive symptoms, AUC 0.61-0.68 for frequent ED visits, AUC 0.66-0.68 for frequent hospitalization, AUC of 0.71 for frequent use of community services(37),high acute care utilization AUC 0.68(38); *TRST* score AUC 0.626-0.640 and *VIP* score AUC 0.588-0.654 for functional decline > 65 years admitted to hospital via ED(36); *SHERPA* for >70 admitted via ED AUC 0.73 for functional decline at 3 months(39); *HARP* >70 admitted to hospital AUC 0.65 for functional decline(40);

Studies of frailty scales in the hospital ward setting report slightly better predictive powers, but these scales might reflect a sub-selected (and therefore possibly more frail), and in most instances, older patient population : >70 years admitted to geriatric unit by clinical judgement for composite outcome of mortality OR admission to residential care facility OR transfer from low to high care within residential facility at discharge *FI-CD* AUC 0.735, *Katz* AUC 0.704, *CHS* AUC 0.675*, SOF* AUC 0.679*, FRAIL* AUC 0.638*, FI-CGA-10* AUC 0.617*, Gait* AUC 0.643, *SHERPA* AUC 0.697, *MPI* AUC 0.617 *HARP* AUC 0.639 *CCI* AUC 0.579(41); >50 admitted to ICU *CFS* Odds Ratios(OR) for In-hospital mortality(1.81), adverse events(1.54), 1-year mortality(1.82), low Quality of Life score(1.98) and Functional dependence(2.25)(42); *FI* for patients admitted with hip fracture AUC 0.82 for failure to return home at 30 days(43); > 65 admitted to hospital MPI AUC 0.76, FI-SOF AUC 0.68, FI-CD AUC 0.73, FI-CGA AUC 0.72 for all cause mortality at 1 month(44); >80 admitted to hospital for at least 48 hours via ED AUC 0.81 for

functional decline at 2 months(45); >70 years admitted to acute geriatric ward CHS OR for mortality at 6 months *CHS (*4.68), *SOF(* 1.97); >75 admitted to acute care hospital, for every 1% increase in *FI* is associated with a 5% increase in risk of death(46).

We noted a phenomenon of improved predictive power reflected with in-spell models compared to historic models for both Charlson Co-morbidity scores and Frailty Syndromes. There may be 2 causes. Firstly, HES data is coded at discharge not admission. Diagnostic coding in HES may improve throughout the patients in-hospital stay with in-spell coding methodology adding an extra admission as a window for this to happen. Secondly, there may be "leak" from the primary diagnostic coding position as these complex patients will likely have several reasons for emergency admission to hospital. Interestingly, taking into account co-morbidity (by way of Charlson co-morbidity score) did not significantly improve predictive power. Variance Inflation Factor Scores suggest only mild collinearity between the Charlson co-morbidity score and frailty syndromes, suggesting mild overlap between the variables.

All our models displayed significance at $p<0.05$ for the Hosmer-Lemeshow tests for Goodness-of-fit test. Similar findings have been described by others who have produced models on HES specifically (25) as the test is recognized to detect unimportant differences within large datasets(47). Ordering the patients by deciles of predicted risk allows a visual representation of the models discrimination.

Limitations

Though HES is a large dataset with high information standards, it has limitations. It is retrospectively coded, thus reflects the patient's condition at discharge from hospital. To counter this, the model inputs data from historic spells to more accurately reflect a risk prediction tool at point of entry to care. Diagnostic coding accuracy in HES has been challenged. Plotting annual trend profiles of the data allowed us to choose a suitable temporal range to develop the model, as well as account for any change in coding practices over time. Even so, the administrative dataset may not accurately reflect the actual clinical situation. Coding inconsistencies will limit the models predictive powers and accuracy. Prospective testing on a clinical dataset is a necessary next step. Though a rich dataset, HES does not contain variables previously identified as being predictive of frailty (e.g. polypharmacy or weakness). This risks excluding potentially relevant variables from the model.

Conclusion

Frailty Syndromes are a valid predictor of outcomes relevant to acute care. We provide a frailty score developed from routinely collected administrative data, and this study adds further understanding and utility for the secondary use of this data. The models predictive power is in keeping with other scores in the literature, but is a simple, clinically relevant and potentially more acceptable measurement for use in the acute care setting. Predictive powers of the score are not sufficient for clinical use, though HES coding quality in HES may be responsible. Prospective testing in a clinical dataset and the addition of other variables known to predict frailty may improve predictive power.

Contributorship:

JS conceived study, designed analysis, interpreted results and wrote first draft
AJP designed analysis, interpreted results, contributed to ongoing writing
SS and KD designed analysis
DB conceived study, designed analysis, interpreted results and contributed to ongoing writing

Competing interests:
The authors have no competing interests to declare

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Transparency Statement

The lead author affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Data Sharing Statement

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Ethics

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.

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Figure Legend:

Figure 1 Percentage mortality by prediction ranking for the Frailty syndromes & admission history model

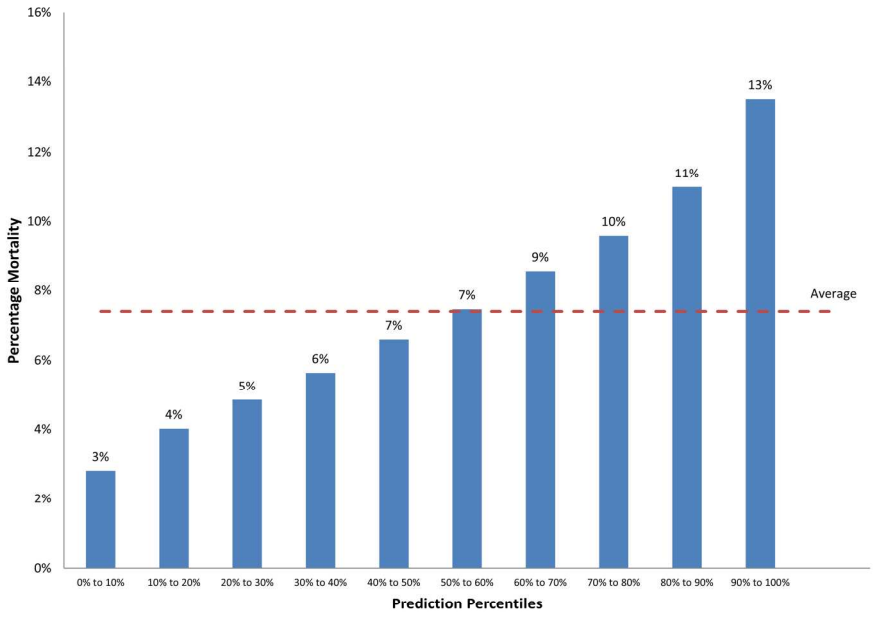
(Figure 1)

Figure 2 Percentage discharged to a higher level of functional dependence (institutionalization) by prediction ranking for the Frailty syndromes & admission source model

(Figure 2)

Figure 3 Percentage with emergency readmission within 30 days by prediction ranking for the Frailty syndromes & admission history model

(Figure 3)



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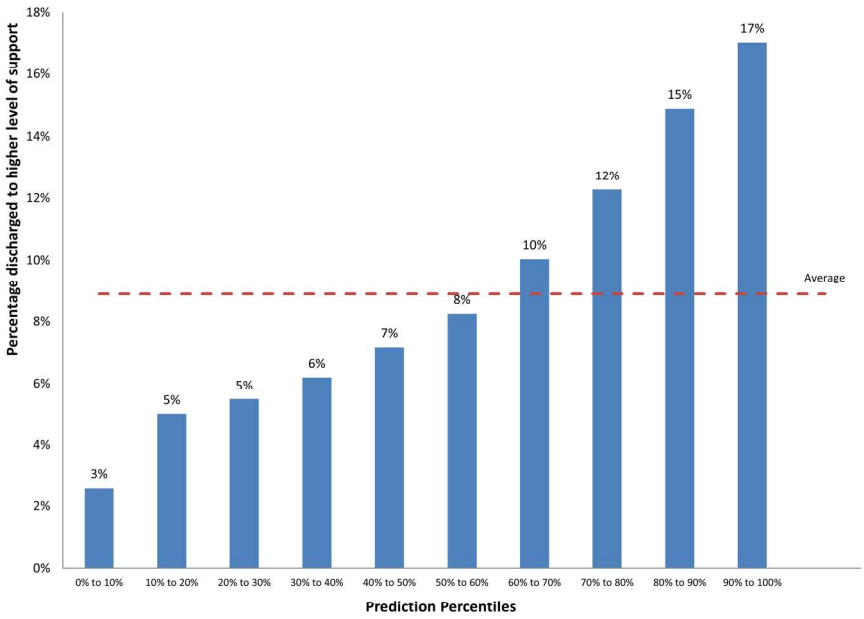

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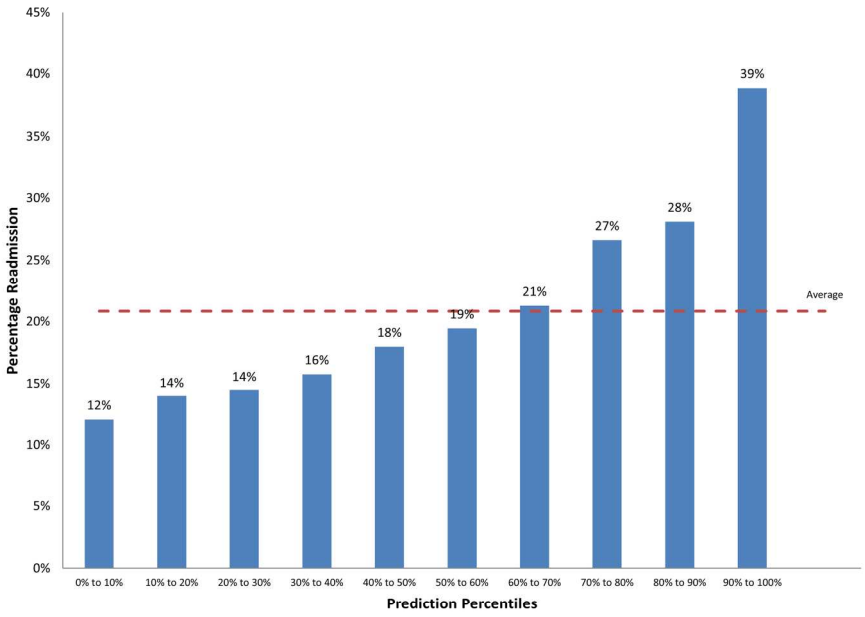

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Appendix 1

Frailty Syndrome	ICD-10 Diagnostic Code
Anxiety and Depression	F320 F320- F320-- F320-D F3200 F3200- F3200A F3200D F3201 F3201A F3201D F3207 F320X F321 F321 1 F321- F321-- F321-D F3210 F3210- F3210A F3210D F3211 F3211- F32110 F32111 F3211A F3211D F3219 F322 F322 D F322- F322-D F32211 F3229 F322X F323 F323 D F323- F323-- F323-D F3230 F3231 F3239 F324 F325 F326 F327 F328 F328 A F328- F3289 F328A F329 F329 A F329 D F329- F329-- F329-A F329-D F329. F329/ F3290 F3292 F3293 F3295 F3296 F3298 F3299 F329A F329D F329J2 F329M F329Q F32X F32X- F33#- F330 F330- F330-D F3300 F3300A F3301 F3301A F3301D F331 F331 1 F331- F331-D F3310 F3310- F3310A F3310D F3311 F3311- F3311A F3311D F332 F332- F332-- F332-D F3320 F3329 F333 F333- F333-D F3330 F3331 F3333 F334 F334- F335 F336 F337 F338 F338- F338-D F3380 F339 F339 A F339- F339-- F339-D F3396 F33X F380 F380- F3800 F3800A F3800D F381 F381- F3810 F3810A F3810D F388 F388- F38X F410 F410- F410-- F4100 F4101 F4103 F410D F411 F411- F411-D F412 F412- F412-- F4122 F412D F413 F413- F418 F418- F419 F419- F419-- F4193 F4199 F419X F41X F430 F430- F430-D F4300 F4301 F4302 F431 F431- F431-- F432 F432 0 F432 2 F432 3 F432 5 F432- F432-- F432-D F4320 F4320A F4320D F4320X F4321 F4321- F4321A F4321D F4322 F4322- F4322A F4322D F4323 F4323A F4323D F4324 F4325 F4325- F4325A F4325D F4328 F4328A F4328D F4329 F432X F438 F438- F439 F439- F43X F440 F440- F441 F441- F442 F442- F4422 F443 F443- F444 F444- F445 F445- F446 F446- F447 F447- F448 F448- F4480 F4481 F4481A F4481D F4482 F4488 F449 F449-
Delirium	F050 F050 A F050- F051 F051 A F051 D F051- F051-A F051-D F0513 F051D F058 F058- F058-- F059 F059 D F059- F059--
Dementia	F000 F000 A F000 D F000* F000+ F000- F000-A F000-D F0000 F00001 F00002 F0000A F0001 F00010 F0001A F0002 F0002A F0003 F00031 F00032 F0004 F00040 F00041 F00042 F0004A F0009 F0009A F000a F001 F001 0 F001 1 F001 A F001 D

	F001* F001+ F001- F001-A F001-D F0010 F00101 F00102 F0010A F0011 F00111 F00112 F0011A F0012 F00122 F0012A F0013 F00130 F00131 F00132 F0014 F00140 F00141 F00142 F0014A F001A F001AG F001D F002 F002 A F002 D F002* F002*A F002+ F002- F002-A F002-D F0020 F0020A F0021 F00211 F0022 F0023 F0023A F0024 F0024A F002A F008 F009 F009 * F009 A F009 D F009* F009+ F009- F009-A F009-D F009.A F0090 F00901 F0090A F0091 F00912 F0091A F0092 F0092A F0093 F0093A F0094 F0094A F009A F009A\ F009AG F009D F009DG F009X F009XA F00A-A F00X F00X- F010 F010* F010- F010-D F0100 F01001 F01002 F0100A F0100D F0101 F01012 F0101A F0101D F0102 F0102A F0102D F0103 F0104 F01042 F0104A F0104D F011 F011 A F011 D F011- F011-- F011-A F011-D F0110 F01100 F01101 F01102 F0110A F0111 F01111 F01112 F0111A F0112 F01120 F01121 F01122 F0113 F01131 F01132 F0114 F01141 F01142 F0114A F0114D F0117 F0119 F011A F011D F012 F012 A F012 D F012- F012-D F0120 F0120A F0121 F01211 F01232 F0124 F012A F013 F013 A F013 D F013* F013- F013-D F0130 F01301 F01302 F0130A F0131 F01310 F01312 F0133 F01330 F0134 F01340 F01341 F01342 F018 F018 A F018- F018-A F0180 F0181 F0182 F0183 F0184 F018D F019 F019 * F019 A F019 D F019* F019- F019-- F019-A F019-D F0190 F0191 F01910 F0192 F01921 F0192A F0193 F0194 F01941 F01942 F0197 F0199 F019A F019D F019N F019Z8 F01X F01X- F02. F020 F020 A F020 D F020* F020- F020-A F020-D F0200 F02001 F0200A F0201 F02012 F0202 F0203 F0203A F0204 F0204A F020A F020D F021 F021 A F021* F021- F021-A F0210 F0211 F0214 F021A F022 F022 A F022 D F022* F022- F022-A F0220 F0220A F0222 F0223 F0224 F022A F023 F023 A F023 D F023* F023+ F023- F023-A F023-D F0230 F02301 F0230A F0231 F0231A F0232 F02320 F02321 F0232A F0233 F02331 F0233A F0234 F02341 F02342 F0234A F023A F023AG F023D F023X F023XA F024 F024 A F024* F024-A F0240 F0241 F02412 F0242A F0243 F0244 F024A F028 F028 ! F028 * F028 A F028 D F028* F028+ F028- F028-A F028-D F0280 F02801 F0280A F0281 F02811 F0281A F0282 F02821 F0282A F0283 F0284 F0284A F028A F028D F028XA F029 F02X F03- F030 F0300 F03011 F0304 F03X F03X * F03X A F03X D F03X* F03X+ F03X- F03X-- F03X-A F03X-D F03X0 F03X0* F03X00 F03X01

		F03X02	F03X0D	F03X1	F03X11	F03X12	F03X2	F03X20	F03X2A
		F03X2D	F03X3	F03X4	F03X41	F03X42	F03X6	F03X9	F03XD
		F03XG	F03XI	F03XS	F03XZ	F04X	F04X-	R410	R410 D
		R410-	R410--	R4100	R4104	R4109	R410D	R410L	R410X
		R411	R411-	R411X	R412	R412-	R413	R413-	R413--
		R418	R418 D	R418-	R418--	R4185			
Functional Dependence	Z741	Z741-	Z742	Z742-	Z7421	Z743	Z743-	Z748	Z748-
		Z749	Z749-	Z74X	Z750	Z750-	Z7500	Z751	Z751-
		Z751--	Z751-D	Z7511	Z7513	Z752	Z752-	Z7520	Z753
		Z753-	Z754	Z754-	Z7548	Z755	Z755-	Z755-D	Z7555
		Z758	Z758-	Z759	Z759-	Z75X			
Falls and Fractures	R55X	R55X D	R55X*	R55X+	R55X-	R55X--	R55X-D	R55X7	R55XA
		R55XD	R55XX	S320	S320 0	S320-	S320-D	S3200	S3200D
		S3201	S3202	S3205	S3206	S3209	S320D	S321	S321 0
		S321 D	S321-	S3210	S3210D	S3211	S32130	S322	S322-
		S3220	S3221	S323	S323 0	S323-	S3230	S3230D	S3231
		S3236	S324	S324 0	S324-	S3240	S3240A	S3240D	S3241
		S324D	S325	S325 0	S325 D	S325-	S325-D	S3250	S3250-
		S3250A	S3250D	S3251	S3252	S3254	S3255	S3256	S3258
		S3259	S327	S327 0	S327-	S3270	S3270D	S3271	S328
		S328 0	S328-	S328-D	S3280	S3280D	S3281	S3288	S32X
		S330	S330-	S331	S331-	S331-D	S3310	S331D	S332
		S332-	S3320	S333	S333-	S3330	S3331	S333D	S334
		S334-	S3340	S335	S335-	S3350	S336	S336-	S337
		S337-	S3370	S33X	S420	S420 0	S420-	S420-A	S4200
		S4200D	S4201	S4201D	S4206	S421	S421 0	S421-	S4210
		S4210-	S4210D	S4211	S4212	S4213	S422	S422 0	S422-
		S4220	S4220-	S4220D	S4221	S42210	S4222	S422O	S423
		S423 0	S423 D	S423-	S4230	S4230D	S4231	S4231D	S4232
		S42340	S4236	S4239	S423D	S424	S424 0	S424-	S4240
		S4240D	S4241	S4241D	S4244	S4248	S4249	S427	S427-
		S4270	S4270D	S4271	S428	S428-	S4280	S4281	S429
		S429 0	S429-	S4290	S4290D	S4291	S4299	S430	S430 0
		S430-	S430--	S4300	S4302	S4309	S430D	S431	S431-
		S4310	S4316	S431D	S432	S432-	S4320	S433	S433-
		S4330	S434	S434-	S4340	S4341	S434D	S435	S435-
		S436	S436-	S436D	S437	S437-	s620	S620 0	S620-
		S6200	S6200D	S6201	S6204	S6208	S621	S621 0	S621-
		S6210	S6211	S6211D	S6218	S622	S622 0	S622-	S6220
		S6220D	S6221	S6221D	S6228	S623	S623 0	S623-	S623--

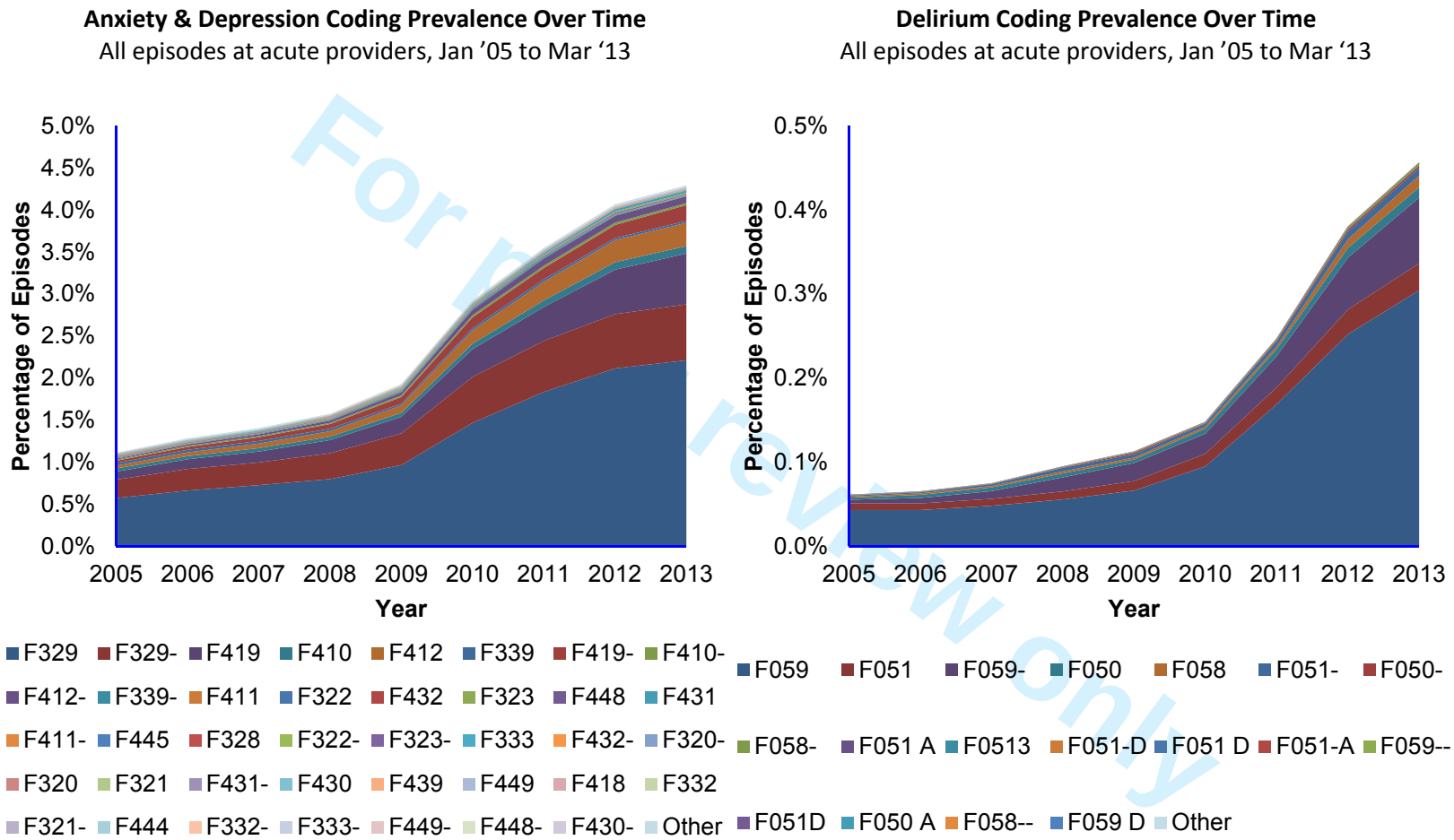
	S6230 S6230D S6231 S6231D S6234 S6236 S6239 S624 S624 0 S624- S6240 S6240D S6241 S6241D S6244 S625 S626- S627 S627 0 S6271 S6274 S628 S628 0 S628- S6280 S6280- S6280D S6281 S6288 S6289 S628O S629 S720 S720 0 S720- S720-D S720.0 S7200 S7200- S72000 S72009 S7200A S7200D S7201 S7201D S7203 S7204 S7205 S7208 S7209 S720A S720D S721 S721 0 S721- S7210 S72100 S7210D S7211 S7215 S7219 S721D S721O S722 S722 0 S722- S7220 S7220D S7221 S72210 S7221D S7222 S723 S723 0 S723 1 S723- S7230 S7230D S7231 S7236 S723D S724 S724 0 S724- S7240 S7240A S7240D S7241 S7246 S727 S727- S7270 S7271 S728 S728 0 S728- S7280 S7280D S7281 S728D S729 S729 0 S729- S7290 S7290D S7291 S7295 S7299 S729D S72X S730 S730- S730-D S7300 S730D S731 S731- S7310 S7315 S731D S73X S73X- W000 W000- W0009 W000A W001 W001- W0010 W0012 W0019 W002 W002- W002A W003 W003- W0033 W003A W004 W004- W0040 W0049 W004A W004D W005 W005- W006 W006- W007 W007- W008 W008- W0080 W008A W009 W009- W0090 W0099 W009A W010 W010 A W010 D W010- W010-A W0100 W0101 W0103 W0104 W0108 W0109 W010A W011 W011- W0111 W0118 W0119 W011A W012 W012- W012-- W0120 W0122 W0123 W0128 W0129 W012A W012X W013 W013- W0130 W0131 W0139 W013A W014 W014- W0140 W0141 W0148 W0149 W014A W015 W015- W0150 W0152 W0158 W0159 W015A W016 W016- W0160 W016A W017 W017- W018 W018- W0180 W0181 W0182 W0185 W0188 W0189 W018A W019 W019- W0190 W0191 W0192 W0195 W0198 W0199 W019A W020 W020- W020A W021 W021- W022 W022- W023 W023- W0230 W0239 W023A W024 W024- W024A W025 W025- W026 W026- W027 W028 W028- W0280 W0281 W0282 W028A W029 W029- W0290 W0291 W0293 W0299 W029A W030 W030- W0300 W0301 W0309 W030A W031 W031- W0319 W031A W032 W032- W0320 W0329 W032A W033 W033- W0330 W0331 W0333 W0339 W033A W034 W034- W0349 W035 W035- W036 W036- W037 W037- W038 W038- W0380 W0383 W038A W039 W039- W0390 W0398 W0399 W039A W040 W040- W0409 W040A W041 W041- W0410 W0419 W042 W042- W0429 W043 W043- W044 W044- W045 W045- W046 W0460 W0469 W047

	W048 W048- W049 W049- W0491 W0499 W049A W050 W050- W0504 W0509 W050A W051 W051- W0519 W051A W052 W052- W0528 W0529 W052A W053 W053- W054 W054- W0549 W054A W055 W055- W056 W056- W057 W057- W058 W058- W0581 W0589 W058A W059 W059- W0598 W0599 W059A W060 W060- W0600 W0601 W0604 W0608 W0609 W060A W061 W061- W061-A W0611 W0619 W061A W062 W062- W062-- W0624 W0628 W0629 W062A W063 W063- W064 W064- W065 W065- W065A W066 W066- W067 W068 W068- W0689 W069 W069- W0690 W0691 W0692 W0699 W069A W070 W070- W0700 W0701 W0706 W0708 W0709 W070A W071 W071- W0711 W0718 W0719 W071A W072 W072- W0720 W0728 W0729 W072A W073 W073- W074 W074- W075 W075- W0752 W0759 W076 W076- W077 W077- W078 W078- W0782 W079 W079- W0790 W0798 W0799 W079A W080 W080- W0808 W0809 W080A W081 W081- W0810 W0819 W082 W082 AW082- W0829 W082A W083 W083- W0830 W084 W084- W085 W085- W0850 W085A W086 W086- W0860 W087 W087- W088 W088- W0889 W089 W089- W0899 W089A W090 W090 AW090- W0900 W0901 W0909 W090A W091 W091- W092 W092- W0920 W0921 W092A W093 W093- W0939 W093A W094 W094- W095 W095- W0959 W095A W096 W096- W097 W097- W098 W098- W0981 W0988 W0989 W098A W099 W099- W0990 W0991 W0999 W099A W100 W100- W100-A W1000 W1008 W1009 W100A W101 W101- W1011 W1012 W1019 W101A W102 W102- W1029 W102A W103 W103 DW103- W1030 W1039 W103A W104 W104- W1049 W105 W105- W1052 W1058 W1059 W105A W106 W106 DW106- W1062 W107 W107- W108 W108- W1082 W1085 W1089 W108A W109 W109- W1090 W1098 W1099 W109A W109D W110 W110- W1100 W1103 W1109 W110A W111 W111- W1110 W112 W112 D W112- W113 W113 DW113- W113-D W1130 W1139 W114 W114- W115 W115- W116 W116- W116A W117 W117- W118 W118- W1182 W1183 W1188 W119 W119- W1191 W1192 W1193 W1198 W1199 W119A W120 W120- W120A W121 W121- W122 W122- W123 W123- W124 W124- W125 W125- W126 W126- W126A W127 W127- W128 W128- W129 W129- W1292 W1299 W129A W130 W130- W1300 W1304 W1308 W1309 W130A W131 W131-

	W131A W132 W132- W1329 W133 W133- W1339 W134 W134- W1349 W135 W135- W136 W136- W1360 W137 W137- W138 W138- W1389 W138A W139 W139- W1390 W1392 W1393 W1399 W139A W140 W140- W140A W141 W141- W142 W142- W143 W143- W144 W144- W1449 W145 W145- W146 W146- W147 W147- W148 W148- W1482 W148A W149 W149- W1490 W1499 W149A W150 W150- W151 W151- W152 W152- W153 W153- W1530 W154 W154- W155 W156 W156- W157 W158 W158- W159 W159- W1590 W160 W160- W161 W161- W162 W162- W163 W163- W164 W164- W165 W165- W166 W166- W167 W167- W168 W168- W169 W169- W170 W170- W1700 W1701 W1708 W1709 W170A W171 W171- W172 W172- W1720 W1729 W172A W173 W173- W1730 W1739 W173A W174 W174- W1740 W1749 W174A W175 W175- W1752 W175A W176 W176- W1762 W1769 W176A W177 W177- W178 W178- W1780 W1781 W1782 W1789 W178A W179 W179- W1790 W1791 W1792 W1798 W1799 W179A W180 W180- W180-A W1800 W1801 W1802 W1803 W1804 W1808 W1809 W180A W180E W181 W181- W1810 W1811 W1819 W181A W181D W182 W182- W182-- W1820 W1821 W1822 W1828 W1829 W182A W183 W183- W1830 W1831 W1839 W183A W184 W184- W1840 W1848 W1849 W184A W185 W185- W1851 W1858 W1859 W185A W186 W186- W1869 W187 W187- W1879 W188 W188- W1880 W1881 W1882 W1883 W1888 W1889 W188A W189 W189- W1890 W1891 W1892 W1893 W1894 W1895 W1898 W1899 W189A W190 W190 AW190 DW190- W190-- W190-A W190-D W1900 W1901 W1903 W1905 W1908 W1909 W190A W191 W191- W191-A W1910 W1911 W1918 W1919 W191A W192 W192 DW192+ W192- W192-- W192-A W1921 W1922 W1928 W1929 W192A W193 W193- W1930 W1939 W194 W194* W194- W1940 W1941 W1943 W1948 W1949 W194A W195 W195- W1959 W195A W196 W196- W196A W197 W197- W197A W198 W198- W198-A W1980 W1981 W1982 W1988 W1989 W198A W199 W199 0 W199 DW199- W199-A W199-D W1990 W1991 W1992 W1993 W1994 W1995 W1996 W1998 W1999 W199A W199D W19X
Incontinence	R15X R15X A R15X D R15X- R15X-- R15X9 R32X R32X- R32X--

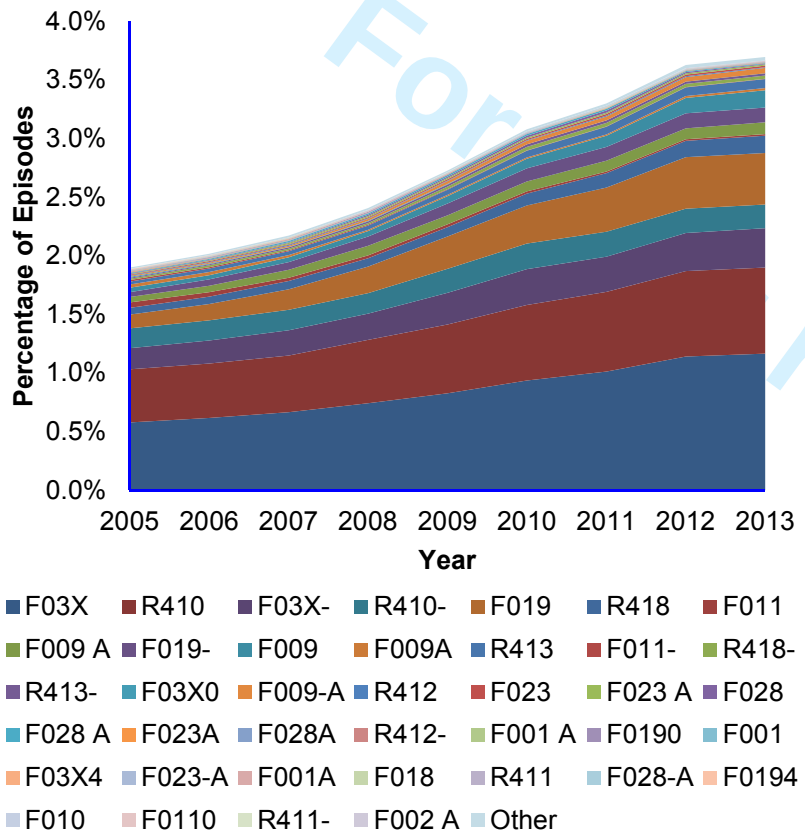
		R32X-A	R32X-D	R32X0	R32X1	R32X3	R32X9	R32XD	
Mobility problems	R260	R260-R2621	R260D R2623	R261 R263	R261-R263-	R261D R263D	R262 R268	R262 A R268-	R262-R268--
		R2683	R2686	R2689	R268D	R269	Z740	Z740 Z	Z740-
		Z740--	Z740-D	Z740.	Z7400	Z7401	Z7404	Z740C	Z740D
Pressure Ulcers	L890	L890-L892--	L890-- L893	L890D L893-	L891 L893-A	L891- L899	L891-- L899 A	L892 L899-	L892-L899--
		L89X	L89X -	L89X A	L89X D	L89X E	L89X I	L89X J	L89X Z
		L89X-	L89X--	L89X-D	L89X1	L89X5	L89X9	L89XD	
Senility	R54X	R54X A R54X9	R54X D R54XA	R54X- R54XD	R54X-D R54XI	R54X. R54XW	R54X0 R54XX	R54X6	R54X7

APPENDIX 2:



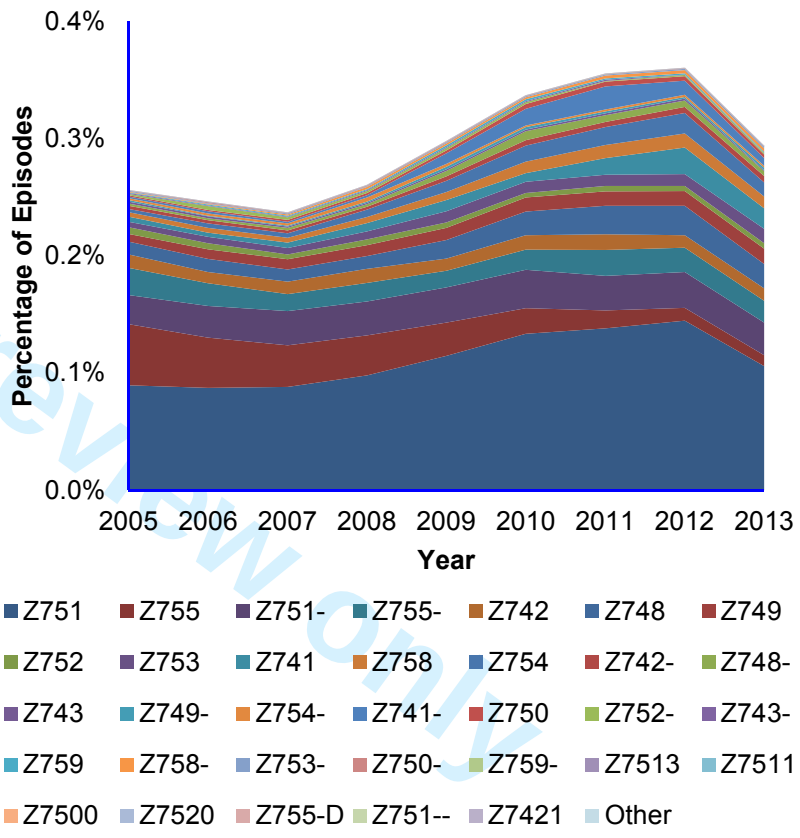
Dementia Coding Prevalence Over Time

All episodes at acute providers, Jan '05 to Mar '13



Functional Dependence Coding Prevalence Over Time

All episodes at acute providers, Jan '05 to Mar '13

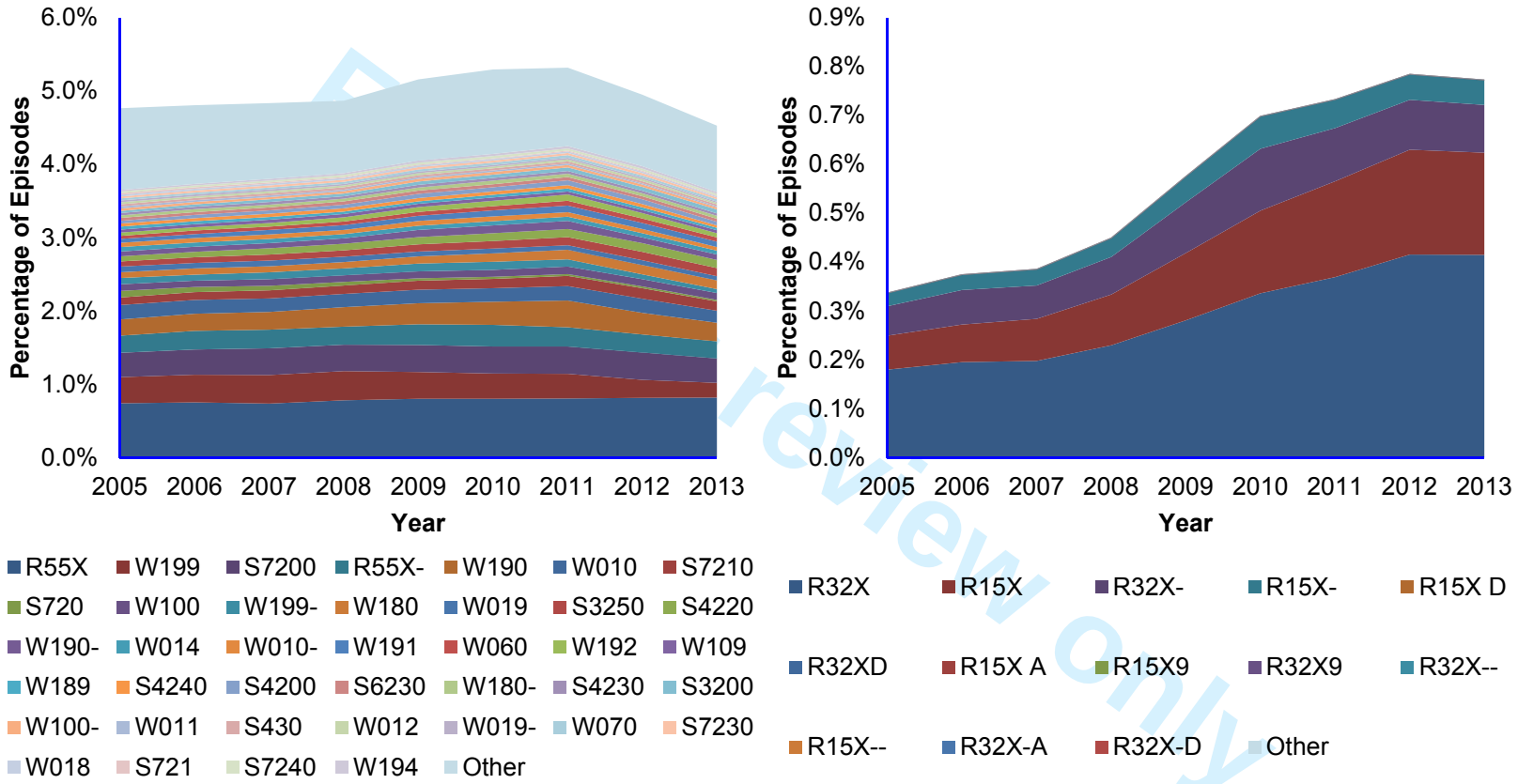


Falls (& significant fracture) Coding Prevalence Over Time

All episodes at acute providers, Jan '05 to Mar '13

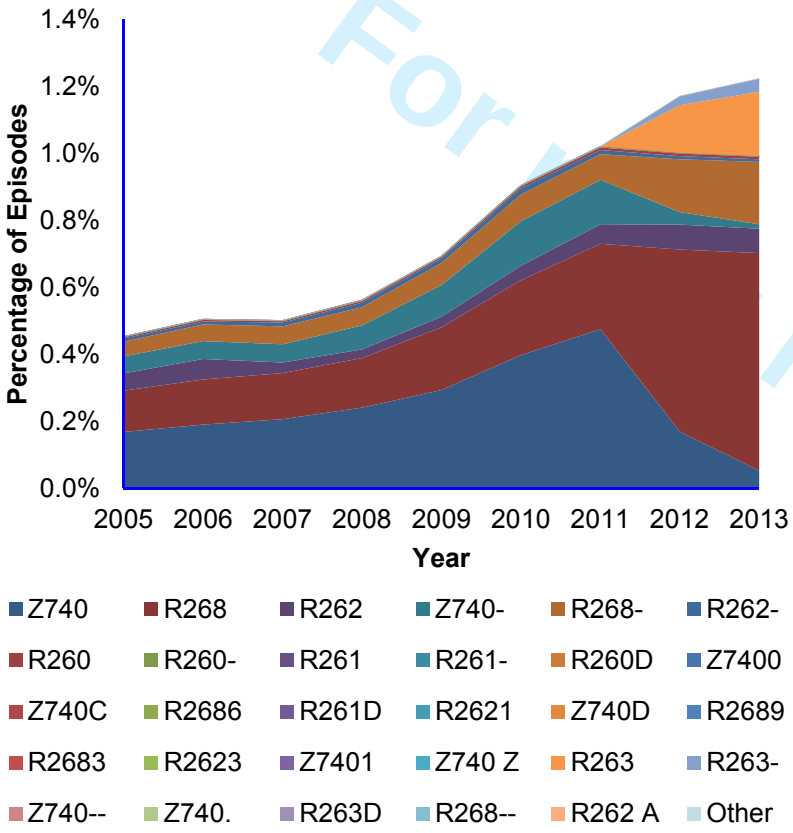
Incontinence Coding Prevalence Over Time

All episodes at acute providers, Jan '05 to Mar '13



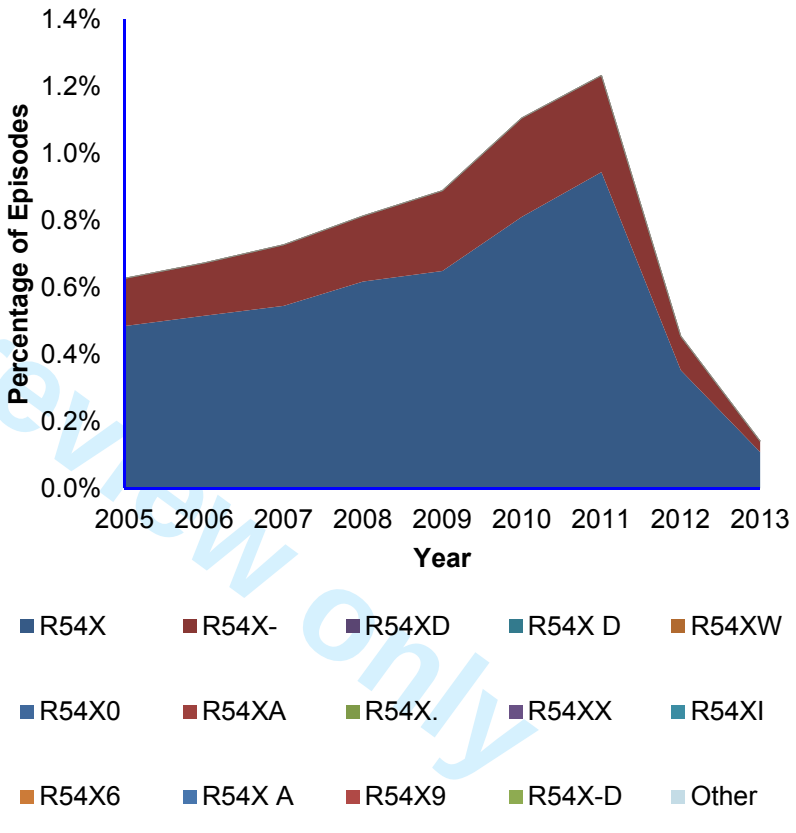
Mobility Problems Coding Prevalence Over Time

All episodes at acute providers, Jan '05 to Mar '13



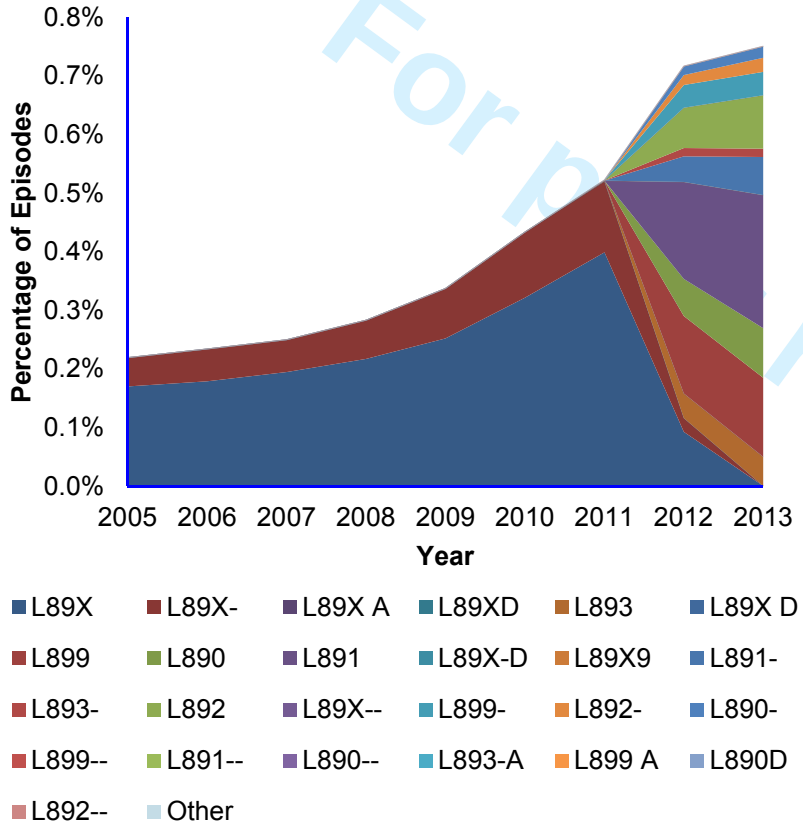
Senility Problems Coding Prevalence Over Time

All episodes at acute providers, Jan '05 to Mar '13



Pressure Ulcers Coding Prevalence Over Time

All episodes at acute providers, Jan '05 to Mar '13



STROBE 2007 (v4) checklist of items to be included in reports of observational studies in epidemiology*

Checklist for cohort, case-control, and cross-sectional studies (combined)

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Page 1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Page 2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Page 3
Objectives	3	State specific objectives, including any pre-specified hypotheses	Page 3
Methods			
Study design	4	Present key elements of study design early in the paper	Pages 3-7
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Page 4
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	Page 4
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Page 4-7, Appendix 1
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Page 5-6, Appendix 1
Bias	9	Describe any efforts to address potential sources of bias	Page 4, Page 18
Study size	10	Explain how the study size was arrived at	Page 4, Page 7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Page 4, Page 7
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	Page 7
		(*b*) Describe any methods used to examine subgroups and interactions	Page 7
		(*c*) Explain how missing data were addressed	Page 7
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed	N/A

		Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	Page 7
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Page 4, Page 7
		(b) Give reasons for non-participation at each stage	N/A
		(c) Consider use of a flow diagram	N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	N/A
		(b) Indicate number of participants with missing data for each variable of interest	Page 7
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	N/A
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	N/A
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	N/A
		Cross-sectional study—Report numbers of outcome events or summary measures	Page 7-14
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Page 7, Page 9-14
		(*b*) Report category boundaries when continuous variables were categorized	N/A
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Page 8, Page 10
Discussion			
Key results	18	Summarise key results with reference to study objectives	Page 16-17
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 18
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Pages 15-18
Generalisability	21	Discuss the generalisability (external validity) of the study results	Pages 15-18
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Page 21

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.
Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Developing and validating a risk prediction model for acute care based on frailty syndromes

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Primary Subject Heading:	Geriatric medicine
Secondary Subject Heading:	Health policy, Patient-centred medicine, Research methods
Keywords:	Frailty Syndromes, Risk Prediction, Acute, Outcomes, Model

1

Title: Developing and validating a risk prediction model for acute care based on frailty syndromes

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Figures: 3

Tables: 8

Supplementary: 1

References: 50

ABSTRACT:

Objectives: Population ageing may result in increased co-morbidity, functional dependence and poor quality of life. Mechanisms and pathophysiology underlying frailty have not been fully elucidated, thus absolute consensus on an operational definition for frailty is lacking. Frailty scores in the acute medical care setting have poor predictive power for clinically relevant outcomes. We explore the utility of frailty syndromes (as recommended by national guidelines) as a risk prediction model for the elderly in the acute care setting

Setting: English Secondary Care emergency admissions to NHS acute providers

Participants: There were N=2099252 patients over 65 years with emergency admission to NHS acute providers from 01/01/2012 to 31/12/2012 included in the analysis.

Primary and secondary outcome measures: Outcomes investigated include inpatient mortality, 30Day emergency readmission and institutionalisation. We used pseudorandom numbers to split patients into train (60%) and test (40%). Receiver Operator Characteristics Curves (ROC) and ordering the patients by deciles of predicted risk was used to assess model performance.

Using English Hospital Episode Statistics (HES) data, we built multivariable logistic regression models with independent variables based on frailty syndromes (ICD-10 coding), demographics and previous hospital utilization. Patients included were those >65yrs with emergency admission to acute provider in England (2012).

Results: Frailty syndrome models exhibited ROC scores of 0.624 – 0.659 for inpatient mortality, 0.63 – 0.654 for institutionalisation and 0.57-0.63 for 30 Day emergency readmission.

Conclusion: Frailty Syndromes are a valid predictor of outcomes relevant to acute care. The models predictive power is in keeping with other scores in the literature, but is a simple, clinically relevant and potentially more acceptable measurement for use in the acute care setting. Predictive powers of the score are not sufficient for clinical use

Key Words: Frailty Syndromes, risk prediction, acute, outcomes, model

Article Summary

- Frailty scores in the acute medical care setting have poor predictive power for clinically relevant outcomes. We explore the utility of frailty syndromes (as recommended by national guidelines) as a risk prediction model for the elderly in the acute care setting
- The model was developed on routinely collected whole population English administrative data (HES) - all spells for patients over 65 years with emergency admission to NHS acute providers from 01/01/2012 to 31/12/2012(N=2099252).
- Frailty syndrome models exhibited ROC scores of 0.624 – 0.659 for inpatient mortality, 0.63 – 0.654 for institutionalisation and 0.57-0.63 for 30 Day emergency readmission.
- Frailty Syndromes are a valid predictor of outcomes relevant to acute care. The models predictive power is in keeping with other scores in the literature. However, predictive powers of the score are not sufficient for clinical use.

Strengths and limitations of this study

- It is a simple clinical model that has moderate predictive powers outcomes relevant to acute medical care. It has reduced data requirements compared to existing frailty models trialled in the acute care setting with predictive powers evenly spread over three outcomes
- It is a model designed to be that could be applied at point of access to acute care, does not rely on self reported data and was derived from whole population data that is routinely collected
- This study adds to emerging knowledge surrounding the secondary use of administrative data. It provides a novel methodology to best utilize routinely collected data in a systematic and robust manner that minimizes limitations and optimizes data quality and reliability.
- HES is retrospectively coded, thus reflects the patient's condition at discharge from hospital.
- Diagnostic coding accuracy in HES has been challenged.

Title: Developing and validating a risk prediction model for acute care based on frailty syndromes

Introduction

In the majority of countries the population is living to a greater age. This change in population demographics is not necessarily associated with failing health as individual variation exists. A recent survey indicates that the majority of those over 80 years are satisfied or very satisfied with their health(1). For some, however, this is associated with an increase in co-morbidity(2) and functional dependence(3), with a consequent higher health and social care cost. A large component of this increased need is reflected in hospital demand both for elective and non-elective care. Patients over the age of 65 constitute two thirds of admissions, 40% of all hospital bed days and 65% of NHS spend in acute care(4). Within this population there is group of patients that most clinicians and the public would regard or recognise as frail and at higher risk of adverse outcomes.

Much research has taken place in understanding the pathophysiology and mechanisms underlying frailty(5, 6), however assessing frailty reliably remains problematic and is a research priority (7-13). This is compounded at present by the absence of consensus on an operational definition of frailty (14-16). Two broad approaches to measuring frailty have been described; a specific biophysical phenotype(unintentional weight loss, exhaustion, weakness, slowness, and low physical activity)(17) and an index of accumulated deficit model(18). These models have the benefit of reproducibility, and predict important health outcomes such as mortality, self-reported health and functional dependency (19). Though overlap exists between these models(20), to date, published scores based on these operational definitions demonstrate only poor to moderate predictive powers for adverse outcomes within the acute medical care setting(9). Developing a reliable and clinically acceptable method to quantify frailty that links to outcomes would help in clinical practice as well as provide a method for longitudinal population analysis.

Within elderly care there are a number of syndromes that are commonly recognised in older person, including “Giants of geriatrics”(21) or geriatric syndromes(5). These are common clinical presentations of multi-factorial ill-defined processes recognized in older persons. They include cognitive impairment, pressure ulcers, mobility problems, falls and incontinence. Conceptually, they represent a final common pathway of concentric, non-linear processes formed by the interaction between aetiological and physiological mechanisms, as yet not fully elucidated(5). When complex systems fail, high-order systems tend to break down first(22). This potentially makes frailty syndromes a robust marker for this vulnerable patient cohort. In the acute care setting, they are associated with increased functional dependence and length of hospital stay(23). Current National guidelines for the care of the older person in acute care recommend using frailty syndromes as a possible methodology to assess for frailty(11, 12).

This study explores the hypothesis that frailty syndromes are a valid measure of adverse health outcomes in older persons within the acute care population in England using routinely available secondary care data based on Hospital Episode Statistics (HES)(24). We aim to develop and validate a model of frailty based on these syndromes as the first steps of developing a sensitive clinically relevant assessment tool to be used at point of access of acute care. We aim to evaluate its predictive power for

clinical outcomes relevant to acute medical care. For construct validity(25), we explore its association with the Charlson co-morbidity Score(26).

Methods

Data Source

Hospital Episode Statistics(HES) is an administrative dataset collected for the secondary care setting that has high levels of data completeness and rigorous data cleaning processes, ensuring high data quality. Each record in HES corresponds to a finished consultant episode, during which a patient is under the care of an individual consultant. These episodes were aggregated into hospital spells covering the entirety of a patient's length of stay in a hospital using established methodology(27).

HES contain 20 fields per record for diagnoses codes that are defined in the tenth revision of the International Statistical Classification of Diseases, Injuries and Causes of Death (ICD-10). We systematically explored all 20 diagnostic fields within HES for ICD-10 diagnostic codes to group together to form frailty syndromes (Appendix 1). To explore the effect of coding shifts over time within HES (thereby potentially affecting coding reliability), annual trend profiles for the grouped ICD-10 diagnostic codes were plotted from January 2005 to March 2013. (Appendix 2). As a result of this analysis, data from the years 2010-2012 was selected for the final model, and we merged ICD-10 diagnostic codes for dementia, delirium and senility to form a unified frailty syndrome (cognitive impairment).

Emergency admissions were defined as those for which the method of admission was recorded as 'Emergency', either via accident and emergency services, a general practitioner, a Bed Bureau, a consultant outpatient clinic or other means (HES Column header: *admimeth*=21, 22, 23, 24, 28).

The final risk prediction model included all spells for patients over 65 years with emergency admission to English NHS acute providers from 01/01/2012 to 31/12/2012(N=2099252).

Model input and output variables

Table 1 describes predictor variables for study, including patient demographics, frailty syndromes and previous service use. Table 2 describes outcome variables under investigation, including inpatient mortality, 30-Day emergency readmission and increase functional dependence at discharge (measured as a change in discharge destination to an institution providing more social and functional support when compared to admission source). In the UK, Residential Homes are care homes that provide accommodation, meals and some personal care. Nursing Homes are residential care homes, but additionally have registered nurses that provide care for more complex needs. English care homes can be privately-owned, third sector, local authority or NHS owned. In England, cost for local authority Part 3 residential accommodation is charged to the resident.

Table 1 Predictor inputs for frailty risk prediction model (independent variables)

Name	Time Span	Description	Comments
Age	Current Spell	The startage field from HES	
Sex	Current Spell	The sex field from HES	
Admission Source	Current Spell	The admiSorc field from HES	
Charlson (Historic)	24 Month Historic Average	Calculated per spell, using all diagnoses from all episodes and then averaged. Excludes the current spell	
Charlson (Current)	Current Spell	Calculated using diagnoses in positions 2-20 from all episodes in the spell	
Anxiety & Depression	24 Month Historic Binary Indicator	A binary flag indicating whether a relevant diagnosis has been received during any inpatient spell in the past 24 months	Senility, Dementia and Delirium merged to form the Cognitive Impairment indicator because of changes in coding over time
Cognitive Impairment			
Dependence			
Falls & Fracture			
Incontinence			
Mobility Problems			
Pressure Ulcers			
No. of Emergency Admissions	12 Month Historic Count	The number of emergency admission spells in the previous 12 months, excluding the current spell	Normalised
Days since Last Emergency Admission	24 Month Historic	The number of days since the patient's last discharge from an emergency admission	Normalised. Default value used when the patient hasn't had an emergency admission in the previous 24 months

Table 2 Predictor outputs of frailty risk prediction model (dependant variables)

Name	Time Span	Description	Comments
Inpatient Mortality	Current Spell	Indicates if the discharge destination was death	
30 Day Emergency Readmission	30 days from discharge	Indicates if the patient had an emergency admission within 30 days of discharge from the current spell	
Increase in Functional Dependence	Current Spell	Binary outcome-indicates if the patient's discharge destination was associated with a higher level of functional dependence than the admission source	See functional dependence tiers below

Tier	Values In Tier
1	• The usual place of residence, including no fixed abode • Temporary place of residence when usually resident elsewhere, for example, hotels and residential educational establishments
2	• Local authority Part 3 residential accommodation: where care is provided • Non-NHS (other than Local Authority) run residential care home
3	• NHS run nursing home, residential care home or group home • Non-NHS (other than Local Authority) run nursing home
4	• NHS other hospital provider: ward for general patients or the younger physically disabled or A&E department • Non-NHS run hospital
5	• Non-NHS (other than Local Authority) run hospice

The model consisted of both historical and within-spell variables. Historical variables included data up to 24 months prior to admission spell in 2012, while within-spell variables were only measured during the patients' admission spell in 2012. Historical diagnostic codes were chosen over in-spell ones when coding for frailty syndromes as this more accurately described a risk prediction model at the point of access to acute care. Charlson co-morbidity scores were calculated in HES using previously described methodology(28), using weightings originally described by Charlson (26).

Spells ending with inpatient mortality were excluded when predicting institutionalisation or readmission within 30 days. Spells where the admission source or discharge destination could not be allocated a tier were also excluded when calculating functional dependence (approximately <1% of spells not ending in mortality).

Model development and testing

Pseudorandom numbers split patients into train (60%) and test (40%) groups. We then split spells into train (1,259,185 spells) and test (840,067 spells) sets based upon the groupings (to ensure no patient appears in both train and test sets). Multi-collinearity between predictor variables was investigated by Variance Inflation Factor (VIF), where VIF scores of over 3 were taken to denote unacceptable collinearity. Scikit-learn(29) implementation of logistic regression with l2 regularisation was used to create the risk prediction model. The model co-efficients selected in the train set were then used to score all samples in the test set. Finally, Receiver Operator Characteristic(ROC) curves and Area Under the Curve(AUC) scores(30) were generated based upon the predicted probabilities within the test set scores. Hosmer-Lemeshow(31) tests with scipy implementation of Pearson's chi-squared test were performed for goodness-of-fit. Ordering the patients by deciles of predicted risk allows a visual representation of the models discrimination.

Results

Mortality

None of the models predictor variables (patient demographics, frailty syndromes, previous service use) demonstrated unacceptable collinearity (1.1-2.8)[TABLE 3]. Table 4 describes the predictive power of various frailty syndromes models for within spell in-patient mortality (range of AUCs 0.624 – 0.659). The frailty syndromes & admission history model demonstrates moderate discriminatory power, with the top 10% of patients identified at highest risk of inpatient mortality having a mortality rate (13%) nearly twice the average population (7%)[FIGURE 1]. The addition of Charlson Co-morbidity Score did not significantly improve the predictive power of the model (AUC 0.641). However, in-spell Charlson and Frailty Syndrome models described slightly improved predictive power over historical models (Table 4 and 5).

Table 3 Variance inflation factor scores for predictor variables

Variance Inflation Factor Scores	
Age	2.6
Sex	1.8
Historic Charlson	1.1
Anxiety & Depression	1.7
Cognitive Impairment	1.1
Dependence	1.6
Fall	1.1
Incontinence	1.2
Mobility	1.1
Pressure Ulcers	1.8

Table 4 Frailty syndrome models to predict within spell in-patient mortality

Model	Odds Ratios		AUC
Historical Frailty Syndromes Model	Age	1.05	0.624
	Sex	1.30	
	Anxiety & Depression	0.94	
	Cognitive Impairment	1.21	
	Functional Dependence	1.11	
	Falls & Fracture	0.94	
	Incontinence	1.06	
	Mobility Problems	1.08	
	Pressure Ulcers	1.29	
In-Spell Frailty Syndromes Model	Age	1.05	0.659
	Sex	1.20	
	Anxiety & Depression	0.93	
	Cognitive Impairment	1.40	
	Functional Dependence	0.64	
	Falls & fracture	0.65	
	Incontinence	1.34	
	Mobility Problems	1.16	
	Pressure Ulcers	4.04	

Model	Odds Ratios		AUC
Historical Frailty Syndromes & Charlson Co-morbidity Scores	Age	1.05	0.641
	Sex	1.09	
	Charlson	1.20	
	Anxiety & Depression	0.98	
	Cognitive Impairment	1.01	
	Functional Dependence	1.02	
	Falls & Fracture	0.97	
	Incontinence	1.01	
	Mobility Problems	1.01	
	Pressure Ulcers	1.05	
Historical Frailty Syndromes & Admission History (final model)	Age	1.05	0.632
	Sex	1.21	
	Anxiety & Depression	0.95	
	Cognitive Impairment	1.05	
	Functional Dependence	1.04	
	Falls & fracture	0.90	
	Incontinence	1.02	
	Mobility Problems	1.02	
	Pressure Ulcers	1.11	
	No of Emergency admissions (12m)	0.97	
	Days since last Emergency Admission	0.79	

Table 5 Charlson co-morbidity models to predict within spell in-patient mortality

Model	Odds Ratios		AUC
Historic Charlson	Age	1.05	0.639
	Sex	1.31	
	Charlson	1.20	
In-Spell Charlson	Age	1.05	0.681
	Sex	1.02	
	Charlson	1.29	

Discharge to a higher level of support

Table 6 describes the predictive power of frailty syndrome models to predict discharge to a higher level of support (institutionalization) (range of AUCs 0.63 – 0.654). The frailty syndromes and admission source model demonstrated moderate discriminatory power, with the top 10% of patients identified at highest risk of being discharged to a higher level of support (17%) at nearly twice the average population(9%)[FIGURE 2]. Historic Charlson co-morbidity scores (taking into account age and gender) exhibited AUCs of 0.617.

Table 6 Frailty syndrome models to predict discharge with a higher level of support (institutionalization)

Model	Odds Ratios		AUC
Historic Frailty Syndromes & Admission History	Age	1.04	0.634
	Sex	0.94	
	Anxiety & Depression	0.98	
	Cognitive Impairment	1.36	
	Functional Dependence	1.20	
	Falls & Fracture	1.15	
	Incontinence	1.09	
	Mobility Problems	1.12	
	Pressure Ulcers	1.20	
	No of Emergency Admissions (last 12m)	0.82	
	Days since last Emergency Admission	0.98	
Historic Frailty Syndromes & Admission Source	Age	1.04	0.654
	Sex	0.94	
	Admission Source (x5)	0.42-2.60	
	Anxiety & Depression	0.94	
	Cognitive Impairment	1.36	
	Functional Dependence	1.17	
	Falls & Fracture	1.14	
	Incontinence	1.08	
	Mobility Problems	1.16	
	Pressure Ulcers	1.17	

Model	Odds Ratios		AUC
Historic Frailty Syndromes	Age	1.05	0.63
	Sex	0.95	
	Anxiety & Depression	1.02	
	Cognitive Impairment	1.24	
	Functional Dependence	1.05	
	Falls & Fracture	1.18	
	Incontinence	1.04	
	Mobility Problems	1.09	
	Pressure Ulcers	1.04	

30 Day Emergency readmission

Table 7 describes the predictive power of the frailty models to predict emergency readmission within 30 days (range of AUCs 0.57-0.63). The frailty syndromes and admission history model demonstrated moderate discriminatory power, with the top 10% of patients identified at highest risk of emergency readmission within 30 days (39%) at nearly twice the average population (21%)[FIGURE 3]. Historic Charlson co-morbidity scores (taking into account age and gender) exhibited AUCs of 0.591.

Table 7 Frailty syndrome models to predict emergency readmission within 30 days

Model	Odds Ratios		AUC
Historic Frailty syndromes	Age	1.00	0.574
	Sex	1.20	
	Anxiety & Depression	1.55	
	Cognitive Impairment	1.24	
	Functional Dependence	1.11	
	Falls & Fracture	1.25	
	Incontinence	1.11	
	Mobility	1.35	
	Pressure Ulcers	1.15	

Model	Odds Ratios		AUC
Historic Frailty Syndromes & Admission History	Age	1.00	0.630
	Sex	1.12	
	Anxiety & Depression	1.08	
	Cognitive Impairment	1.05	
	Functional Dependence	1.02	
	Falls & Fracture	1.03	
	Incontinence	1.02	
	Mobility	1.06	
	Pressure Ulcers	1.02	
	No of Emergency Admissions (last 12m)	1.47	
	Days since last Emergency Admission	0.67	

Discussion

Risk stratification of older persons who require acute care is complex and challenging. Reliable recognition of frailty is a research and clinical priority for acute hospital care (7-13) to help inform routine clinical decision making and plan appropriate care. To date, there is no routinely available and reliable clinical score for use within the acute care setting. This study explores the use of internationally recognised frailty syndromes coded within HES data to potentially aid more reliable frailty recognition within the hospital setting. HES data can reliably provide data related to mortality and high resource need (e.g. occupied bed days or readmission). We have constructed a surrogate marker of functional dependency (ie institutionalisation) using available HES fields. The ideal frailty assessment for acute care needs to be comprehensively multidimensional to avoid missing aspects of patient care that may contribute to further decline or harm. It needs to predict outcomes that are relevant to the patient, carers and to acute care providers. To be fit for purpose, it should be optimized for clinical usability: i.e. simple, reliable, does not fully rely on self or carer reported data and possess high sensitivity if functioning as a screening tool. Ideally, there should be the ability to personalize the assessment and "threshold" set to patient preference and previous level of functioning. It should be provide a method to measure frailty over the course of an episode of acute illness and over a patient's life as opposed to single isolated static measures. Ultimately, it should be able to highlight areas for intervention to prevent, reverse or minimize further decline.

Studies exploring the predictive power of frailty scores for outcomes relevant to the UK acute medical care setting [TABLE 8] include prospective observational cohort studies(8, 9, 32) and secondary analysis of routinely collected large datasets, both clinical(33) and administrative(28, 34). Our model performs uniformly across the clinical outcomes and is comparable in predictive power to frailty scores in the same setting. None of the models have predictive powers suitable for clinical risk prediction at the patient's bedside (AUC > 0.80). The exception to this is a single study in the AMU setting in rural Ireland(35), which reported AUCs of >0.8 for 30 day mortality and functional decline but the results of this secondary analysis of a clinical database was not reproduced in prospective observational study at a large teaching centre in the UK(10).

Table 8 Summary of the predictive power of frailty scores in acute care

Model/Scores	Mortality		Re-admission		Functional dependence	
	Inpatient	90 Day	30 Day	90 Day	Institutiona-lisation	≤ 2 points Barthel ADL
AUCs						
Charlson score 2012 (Historic)	0.64		0.59		0.62	
CHS model		0.61		0.52	0.57	0.55
SOF model		0.59		0.53	0.44	0.56
Avila-Funes		0.68		0.55	0.50	0.59
Rothman		0.67		0.53	0.45	0.59
Frailty Index		0.69		0.57	0.55	0.57
ISAR		0.62		0.60	0.65	0.60
PARR30			0.70			
RIGAMA	0.78		0.55		0.50	
Frailty Syndrome Models						
Frailty syndromes and admission source					**0.65**	
Frailty syndromes	**0.62**		**0.57**		**0.63**	
Frailty syndromes and admission history	**0.63**		**0.63**		**0.63**	

Our model has notable strengths. It is a simple clinical model that has moderate predictive powers outcomes relevant to acute medical care. It has less data requirements compared to the Frailty Index(36 input variables)(9), Patient At Risk of Readmission 30-Day(PARR30)(up to 18 input variables)(34), Risk Index for Geriatric Acute Medical Admissions(RIGAMA)(30 inout variables)(33) and Charlson Co-morbidity score(17 input variables)(28). Importantly in comparison to other scores, its predictive power appears to be evenly spread over the three outcomes and does not rely on self-reported data (e.g. Identifying Seniors at Risk (ISAR) score)(36) . It is a model designed to be that could be applied at point of access to acute care. It was derived from whole population data that is routinely collected, with applicability at population and patient level. This study adds to emerging knowledge surrounding the secondary use of administrative data. It provides a novel methodology to best utilize routinely collected data in a systematic and robust manner that minimizes limitations and optimizes data quality and reliability.

Existing frailty scores in the acute care setting have very different input variables (thus likely do not measure the same thing). Optimal outcome variable selection is also yet unclear. For example, our model and most existing frailty scores do not take into account illness severity or disease acuity. We postulate that the addition of variables included in the NEWS(37) score may improve discrimination of frailty models. RIGAMAs (33)notable predictive powers for inpatient mortality may reflect discrimination for acute critical illness given input variables that largely record physiological and metabolic derangement, including prognostic biomarkers (e.g. Troponin). However, it may be that the optimal outcome variable for frailty in acute care is 30-day or 90-day mortality.

Studies of frailty scores in the Emergency Department setting display similar predictive powers for a wide-range of outcomes: *HK-ISAR* >65 years discharged from ED AUC 0.59-0.62 for composite outcome of institutionalisation, re-attendance or death(38); *ISAR* score > 65 years admitted to hospital via ED AUC 0.549-0.584(39), AUC 0.66 for depressive symptoms, AUC 0.61-0.68 for frequent ED visits, AUC 0.66-0.68 for frequent hospitalization, AUC of 0.71 for frequent use of community services(40),high acute care utilization AUC 0.68(41); *TRST* score AUC 0.626-0.640 and *VIP* score AUC 0.588-0.654 for functional decline > 65 years admitted to hospital via ED(39); *SHERPA* for >70 admitted via ED AUC 0.73 for functional decline at 3 months(42); *HARP* >70 admitted to hospital AUC 0.65 for functional decline(43);

Studies of frailty scores in the hospital ward setting report slightly better predictive powers, but these scores might reflect a sub-selected (and therefore possibly more frail), and in most instances, older patient population : >70 years admitted to geriatric unit by clinical judgement for composite outcome of mortality OR admission to residential care facility OR transfer from low to high care within residential facility at discharge *FI-CD* AUC 0.735, *Katz* AUC 0.704, *CHS* AUC 0.675*, SOF* AUC 0.679*, FRAIL* AUC 0.638*, FI-CGA-10* AUC 0.617*, Gait* AUC 0.643, *SHERPA* AUC 0.697, *MPI* AUC 0.617 *HARP* AUC 0.639 *CCI* AUC 0.579(44); >50 admitted to ICU *CFS* Odds Ratios(OR) for In-hospital mortality(1.81), adverse events(1.54), 1-year mortality(1.82), low Quality of Life score(1.98) and Functional dependence(2.25)(45); *FI* for patients admitted with hip fracture AUC 0.82 for failure to return home at 30 days(46); > 65 admitted to hospital MPI AUC 0.76, FI-SOF AUC 0.68, FI-CD AUC 0.73, FI-CGA AUC 0.72 for all cause mortality at 1 month(47); >80 admitted to hospital for at least 48 hours via ED AUC 0.81 for

functional decline at 2 months(48); >70 years admitted to acute geriatric ward CHS OR for mortality at 6 months *CHS (*4.68), *SOF(* 1.97); >75 admitted to acute care hospital, for every 1% increase in *FI* is associated with a 5% increase in risk of death(49).

We noted a phenomenon of improved predictive power reflected with in-spell models compared to historic models for both Charlson Co-morbidity scores and Frailty Syndromes. There may be 2 causes. Firstly, HES data is coded at discharge not admission. Diagnostic coding in HES may improve throughout the patients in-hospital stay with in-spell coding methodology adding an extra admission as a window for this to happen. Secondly, there may be "leak" from the primary diagnostic coding position as these complex patients will likely have several reasons for emergency admission to hospital. Interestingly, taking into account co-morbidity (by way of Charlson co-morbidity score) did not significantly improve predictive power. Variance Inflation Factor Scores suggest only mild collinearity between the Charlson co-morbidity score and frailty syndromes, suggesting mild overlap between the variables.

All our models displayed significance at $p<0.05$ for the Hosmer-Lemeshow tests for Goodness-of-fit test. Similar findings have been described by others who have produced models on HES specifically (28) as the test is recognized to detect unimportant differences within large datasets(50). Ordering the patients by deciles of predicted risk allows a visual representation of the models discrimination.

Limitations

Though HES is a large dataset with high information standards, it has limitations. It is retrospectively coded, thus reflects the patient's condition at discharge from hospital. To counter this, the model inputs data from historic spells to more accurately reflect a risk prediction tool at point of entry to care. Diagnostic coding accuracy in HES has been challenged. Plotting annual trend profiles of the data allowed us to choose a suitable temporal range to develop the model, as well as account for any change in coding practices over time. Even so, the administrative dataset may not accurately reflect the actual clinical situation. Coding inconsistencies will limit the models predictive powers and accuracy. Prospective testing on a clinical dataset is a necessary next step. Though a rich dataset, HES does not contain variables previously identified as being predictive of frailty (e.g. polypharmacy or weakness). This risks excluding potentially relevant variables from the model.

HES does not record specific clinical measures of functional dependency (e.g. Barthel Index). The creation of a 5-tier discharge institution levels represents a pragmatic approach to create an outcome that reflects increase in care need (within HES) as a proxy measure for increase in functional dependency. The premise of comparing discharge institution to admission source within HES as a surrogate for functional dependency is possibly flawed. Cohort and epidemiological studies suggest that there is significant overlap of functional dependency between residents of residential and nursing homes. Additionally, thresholds for transfer into and out of homes in the residential care setting is highly context and health system dependant. For instance, there is marked variation in the manner that criteria for NHS long-term funding is applied between geographical settings. However, the model adds new knowledge surrounding methodologies to utilize routinely collected data for answering clinically meaningful questions.

Conclusion

Frailty Syndromes are a valid predictor of outcomes relevant to acute care. We provide a frailty score developed from routinely collected administrative data, and this study adds further understanding and utility for the secondary use of this data. The models predictive power is in keeping with other scores in the literature, but is a simple, clinically relevant and potentially more acceptable measurement for use in the acute care setting. Predictive powers of the score are not sufficient for clinical use, though HES coding quality in HES may be responsible. Prospective testing in a clinical dataset and the addition of other variables known to predict frailty may improve predictive power. Frailty is an important dimension in risk stratification of older persons requiring acute care.

Contributorship:

JS conceived study, designed analysis, interpreted results and wrote first draft
AJP designed analysis, interpreted results, contributed to ongoing writing
SS and KD designed analysis
DB conceived study, designed analysis, interpreted results and contributed to ongoing writing

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The lead author affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Data Sharing Statement

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Ethics

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.

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Figure Legend:

Figure 1 Percentage mortality by prediction ranking for the Frailty syndromes & admission history model

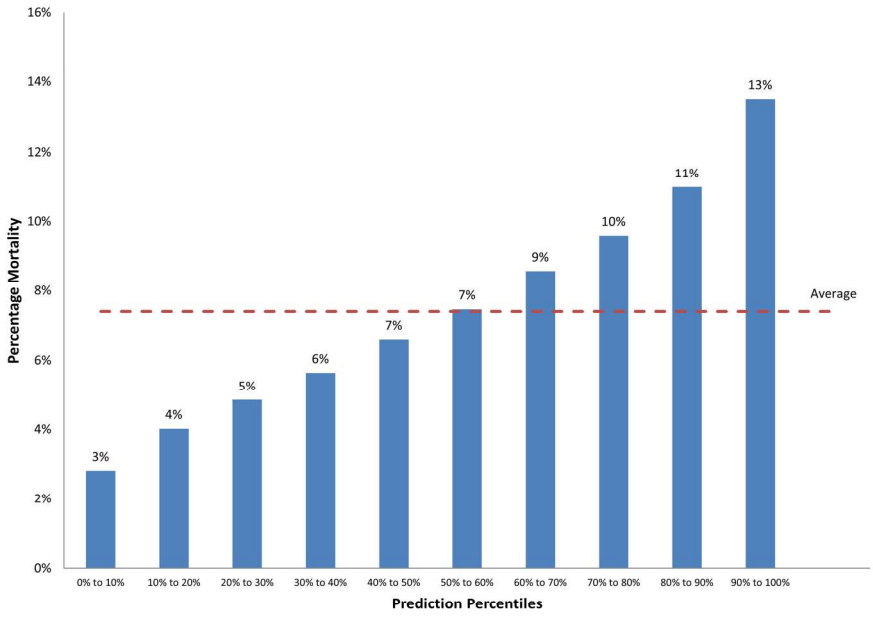
(Figure 1)

Figure 2 Percentage discharged to a higher level of functional dependence (institutionalization) by prediction ranking for the Frailty syndromes & admission source model

(Figure 2)

Figure 3 Percentage with emergency readmission within 30 days by prediction ranking for the Frailty syndromes & admission history model

(Figure 3)



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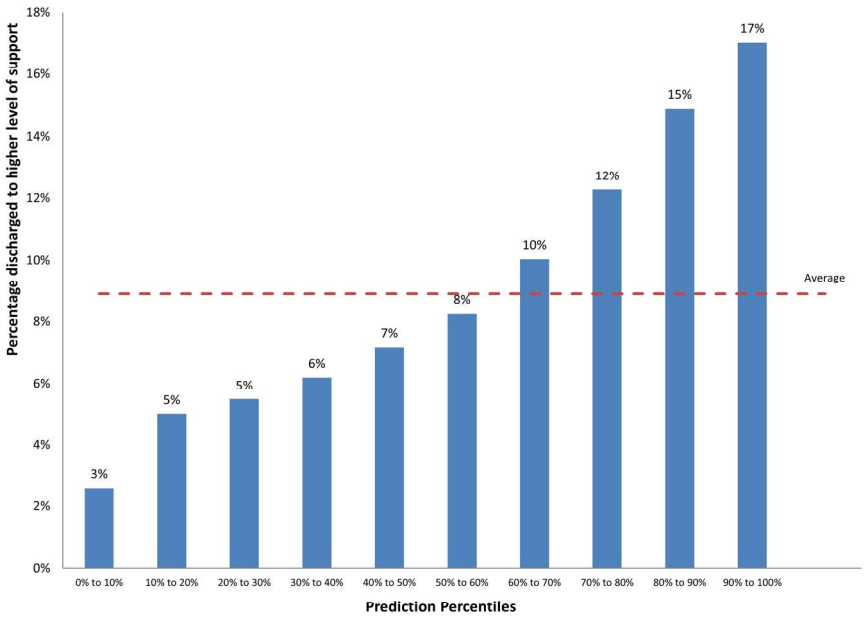

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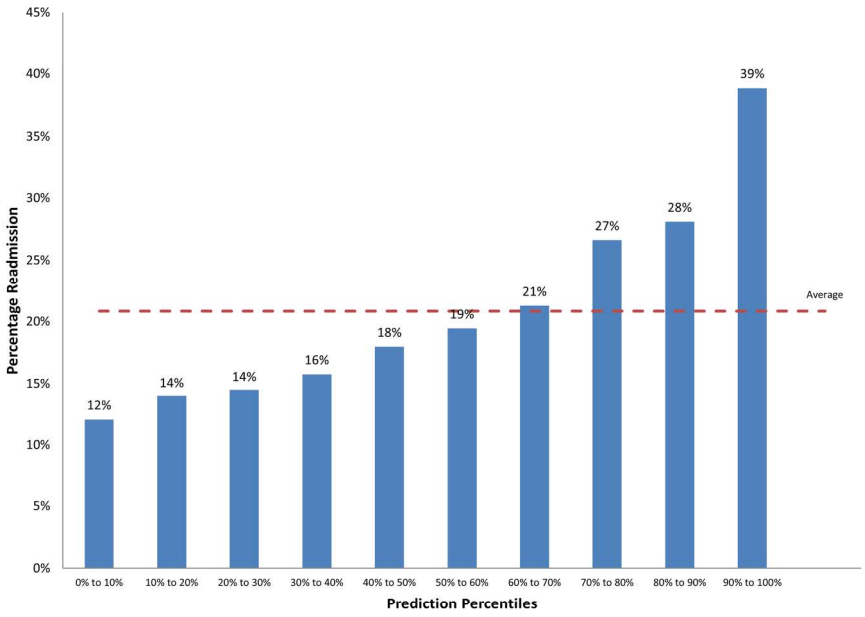

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Appendix 1

Frailty Syndrome	ICD-10 Diagnostic Code
Anxiety and Depression	F320 F320- F320-- F320-D F3200 F3200- F3200A F3200D F3201 F3201A F3201D F3207 F320X F321 F321 1 F321- F321-- F321-D F3210 F3210- F3210A F3210D F3211 F3211- F32110 F32111 F3211A F3211D F3219 F322 F322 D F322- F322-D F32211 F3229 F322X F323 F323 D F323- F323-- F323-D F3230 F3231 F3239 F324 F325 F326 F327 F328 F328 A F328- F3289 F328A F329 F329 A F329 D F329- F329-- F329-A F329-D F329. F329/ F3290 F3292 F3293 F3295 F3296 F3298 F3299 F329A F329D F329J2 F329M F329Q F32X F32X- F33#- F330 F330- F330-D F3300 F3300A F3301 F3301A F3301D F331 F331 1 F331- F331-D F3310 F3310- F3310A F3310D F3311 F3311- F3311A F3311D F332 F332- F332-- F332-D F3320 F3329 F333 F333- F333-D F3330 F3331 F3333 F334 F334- F335 F336 F337 F338 F338- F338-D F3380 F339 F339 A F339- F339-- F339-D F3396 F33X F380 F380- F3800 F3800A F3800D F381 F381- F3810 F3810A F3810D F388 F388- F38X F410 F410- F410-- F4100 F4101 F4103 F410D F411 F411- F411-D F412 F412- F412-- F4122 F412D F413 F413- F418 F418- F419 F419- F419-- F4193 F4199 F419X F41X F430 F430- F430-D F4300 F4301 F4302 F431 F431- F431-- F432 F432 0 F432 2 F432 3 F432 5 F432- F432-- F432-D F4320 F4320A F4320D F4320X F4321 F4321- F4321A F4321D F4322 F4322- F4322A F4322D F4323 F4323A F4323D F4324 F4325 F4325- F4325A F4325D F4328 F4328A F4328D F4329 F432X F438 F438- F439 F439- F43X F440 F440- F441 F441- F442 F442- F4422 F443 F443- F444 F444- F445 F445- F446 F446- F447 F447- F448 F448- F4480 F4481 F4481A F4481D F4482 F4488 F449 F449-
Delirium	F050 F050 A F050- F051 F051 A F051 D F051- F051-A F051-D F0513 F051D F058 F058- F058-- F059 F059 D F059- F059--
Dementia	F000 F000 A F000 D F000* F000+ F000- F000-A F000-D F0000 F00001 F00002 F0000A F0001 F00010 F0001A F0002 F0002A F0003 F00031 F00032 F0004 F00040 F00041 F00042 F0004A F0009 F0009A F000a F001 F001 0 F001 1 F001 A F001 D

	F001* F001+ F001- F001-A F001-D F0010 F00101 F00102 F0010A F0011 F00111 F00112 F0011A F0012 F00122 F0012A F0013 F00130 F00131 F00132 F0014 F00140 F00141 F00142 F0014A F001A F001AG F001D F002 F002 A F002 D F002* F002*A F002+ F002- F002-A F002-D F0020 F0020A F0021 F00211 F0022 F0023 F0023A F0024 F0024A F002A F008 F009 F009 * F009 A F009 D F009* F009+ F009- F009-A F009-D F009.A F0090 F00901 F0090A F0091 F00912 F0091A F0092 F0092A F0093 F0093A F0094 F0094A F009A F009A\ F009AG F009D F009DG F009X F009XA F00A-A F00X F00X- F010 F010* F010- F010-D F0100 F01001 F01002 F0100A F0100D F0101 F01012 F0101A F0101D F0102 F0102A F0102D F0103 F0104 F01042 F0104A F0104D F011 F011 A F011 D F011- F011-- F011-A F011-D F0110 F01100 F01101 F01102 F0110A F0111 F01111 F01112 F0111A F0112 F01120 F01121 F01122 F0113 F01131 F01132 F0114 F01141 F01142 F0114A F0114D F0117 F0119 F011A F011D F012 F012 A F012 D F012- F012-D F0120 F0120A F0121 F01211 F01232 F0124 F012A F013 F013 A F013 D F013* F013- F013-D F0130 F01301 F01302 F0130A F0131 F01310 F01312 F0133 F01330 F0134 F01340 F01341 F01342 F018 F018 A F018- F018-A F0180 F0181 F0182 F0183 F0184 F018D F019 F019 * F019 A F019 D F019* F019- F019-- F019-A F019-D F0190 F0191 F01910 F0192 F01921 F0192A F0193 F0194 F01941 F01942 F0197 F0199 F019A F019D F019N F019Z8 F01X F01X- F02. F020 F020 A F020 D F020* F020- F020-A F020-D F0200 F02001 F0200A F0201 F02012 F0202 F0203 F0203A F0204 F0204A F020A F020D F021 F021 A F021* F021- F021-A F0210 F0211 F0214 F021A F022 F022 A F022 D F022* F022- F022-A F0220 F0220A F0222 F0223 F0224 F022A F023 F023 A F023 D F023* F023+ F023- F023-A F023-D F0230 F02301 F0230A F0231 F0231A F0232 F02320 F02321 F0232A F0233 F02331 F0233A F0234 F02341 F02342 F0234A F023A F023AG F023D F023X F023XA F024 F024 A F024* F024-A F0240 F0241 F02412 F0242A F0243 F0244 F024A F028 F028 ! F028 * F028 A F028 D F028* F028+ F028- F028-A F028-D F0280 F02801 F0280A F0281 F02811 F0281A F0282 F02821 F0282A F0283 F0284 F0284A F028A F028D F028XA F029 F02X F03- F030 F0300 F03011 F0304 F03X F03X * F03X A F03X D F03X* F03X+ F03X- F03X-- F03X-A F03X-D F03X0 F03X0* F03X00 F03X01

		F03X02	F03X0D	F03X1	F03X11	F03X12	F03X2	F03X20	F03X2A
		F03X2D	F03X3	F03X4	F03X41	F03X42	F03X6	F03X9	F03XD
		F03XG	F03XI	F03XS	F03XZ	F04X	F04X-	R410	R410 D
		R410-	R410--	R4100	R4104	R4109	R410D	R410L	R410X
		R411	R411-	R411X	R412	R412-	R413	R413-	R413--
		R418	R418 D	R418-	R418--	R4185			
Functional Dependence	Z741	Z741-	Z742	Z742-	Z7421	Z743	Z743-	Z748	Z748-
		Z749	Z749-	Z74X	Z750	Z750-	Z7500	Z751	Z751-
		Z751--	Z751-D	Z7511	Z7513	Z752	Z752-	Z7520	Z753
		Z753-	Z754	Z754-	Z7548	Z755	Z755-	Z755-D	Z7555
		Z758	Z758-	Z759	Z759-	Z75X			
Falls and Fractures	R55X	R55X D	R55X*	R55X+	R55X-	R55X--	R55X-D	R55X7	R55XA
		R55XD	R55XX	S320	S320 0	S320-	S320-D	S3200	S3200D
		S3201	S3202	S3205	S3206	S3209	S320D	S321	S321 0
		S321 D	S321-	S3210	S3210D	S3211	S32130	S322	S322-
		S3220	S3221	S323	S323 0	S323-	S3230	S3230D	S3231
		S3236	S324	S324 0	S324-	S3240	S3240A	S3240D	S3241
		S324D	S325	S325 0	S325 D	S325-	S325-D	S3250	S3250-
		S3250A	S3250D	S3251	S3252	S3254	S3255	S3256	S3258
		S3259	S327	S327 0	S327-	S3270	S3270D	S3271	S328
		S328 0	S328-	S328-D	S3280	S3280D	S3281	S3288	S32X
		S330	S330-	S331	S331-	S331-D	S3310	S331D	S332
		S332-	S3320	S333	S333-	S3330	S3331	S333D	S334
		S334-	S3340	S335	S335-	S3350	S336	S336-	S337
		S337-	S3370	S33X	S420	S420 0	S420-	S420-A	S4200
		S4200D	S4201	S4201D	S4206	S421	S421 0	S421-	S4210
		S4210-	S4210D	S4211	S4212	S4213	S422	S422 0	S422-
		S4220	S4220-	S4220D	S4221	S42210	S4222	S422O	S423
		S423 0	S423 D	S423-	S4230	S4230D	S4231	S4231D	S4232
		S42340	S4236	S4239	S423D	S424	S424 0	S424-	S4240
		S4240D	S4241	S4241D	S4244	S4248	S4249	S427	S427-
		S4270	S4270D	S4271	S428	S428-	S4280	S4281	S429
		S429 0	S429-	S4290	S4290D	S4291	S4299	S430	S430 0
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		S4310	S4316	S431D	S432	S432-	S4320	S433	S433-
		S4330	S434	S434-	S4340	S4341	S434D	S435	S435-
		S436	S436-	S436D	S437	S437-	s620	S620 0	S620-
		S6200	S6200D	S6201	S6204	S6208	S621	S621 0	S621-
		S6210	S6211	S6211D	S6218	S622	S622 0	S622-	S6220
		S6220D	S6221	S6221D	S6228	S623	S623 0	S623-	S623--

	S6230 S6230D S6231 S6231D S6234 S6236 S6239 S624 S624 0 S624- S6240 S6240D S6241 S6241D S6244 S625 S626- S627 S627 0 S6271 S6274 S628 S628 0 S628- S6280 S6280- S6280D S6281 S6288 S6289 S628O S629 S720 S720 0 S720- S720-D S720.0 S7200 S7200- S72000 S72009 S7200A S7200D S7201 S7201D S7203 S7204 S7205 S7208 S7209 S720A S720D S721 S721 0 S721- S7210 S72100 S7210D S7211 S7215 S7219 S721D S721O S722 S722 0 S722- S7220 S7220D S7221 S72210 S7221D S7222 S723 S723 0 S723 1 S723- S7230 S7230D S7231 S7236 S723D S724 S724 0 S724- S7240 S7240A S7240D S7241 S7246 S727 S727- S7270 S7271 S728 S728 0 S728- S7280 S7280D S7281 S728D S729 S729 0 S729- S7290 S7290D S7291 S7295 S7299 S729D S72X S730 S730- S730-D S7300 S730D S731 S731- S7310 S7315 S731D S73X S73X- W000 W000- W0009 W000A W001 W001- W0010 W0012 W0019 W002 W002- W002A W003 W003- W0033 W003A W004 W004- W0040 W0049 W004A W004D W005 W005- W006 W006- W007 W007- W008 W008- W0080 W008A W009 W009- W0090 W0099 W009A W010 W010 A W010 D W010- W010-A W0100 W0101 W0103 W0104 W0108 W0109 W010A W011 W011- W0111 W0118 W0119 W011A W012 W012- W012-- W0120 W0122 W0123 W0128 W0129 W012A W012X W013 W013- W0130 W0131 W0139 W013A W014 W014- W0140 W0141 W0148 W0149 W014A W015 W015- W0150 W0152 W0158 W0159 W015A W016 W016- W0160 W016A W017 W017- W018 W018- W0180 W0181 W0182 W0185 W0188 W0189 W018A W019 W019- W0190 W0191 W0192 W0195 W0198 W0199 W019A W020 W020- W020A W021 W021- W022 W022- W023 W023- W0230 W0239 W023A W024 W024- W024A W025 W025- W026 W026- W027 W028 W028- W0280 W0281 W0282 W028A W029 W029- W0290 W0291 W0293 W0299 W029A W030 W030- W0300 W0301 W0309 W030A W031 W031- W0319 W031A W032 W032- W0320 W0329 W032A W033 W033- W0330 W0331 W0333 W0339 W033A W034 W034- W0349 W035 W035- W036 W036- W037 W037- W038 W038- W0380 W0383 W038A W039 W039- W0390 W0398 W0399 W039A W040 W040- W0409 W040A W041 W041- W0410 W0419 W042 W042- W0429 W043 W043- W044 W044- W045 W045- W046 W0460 W0469 W047

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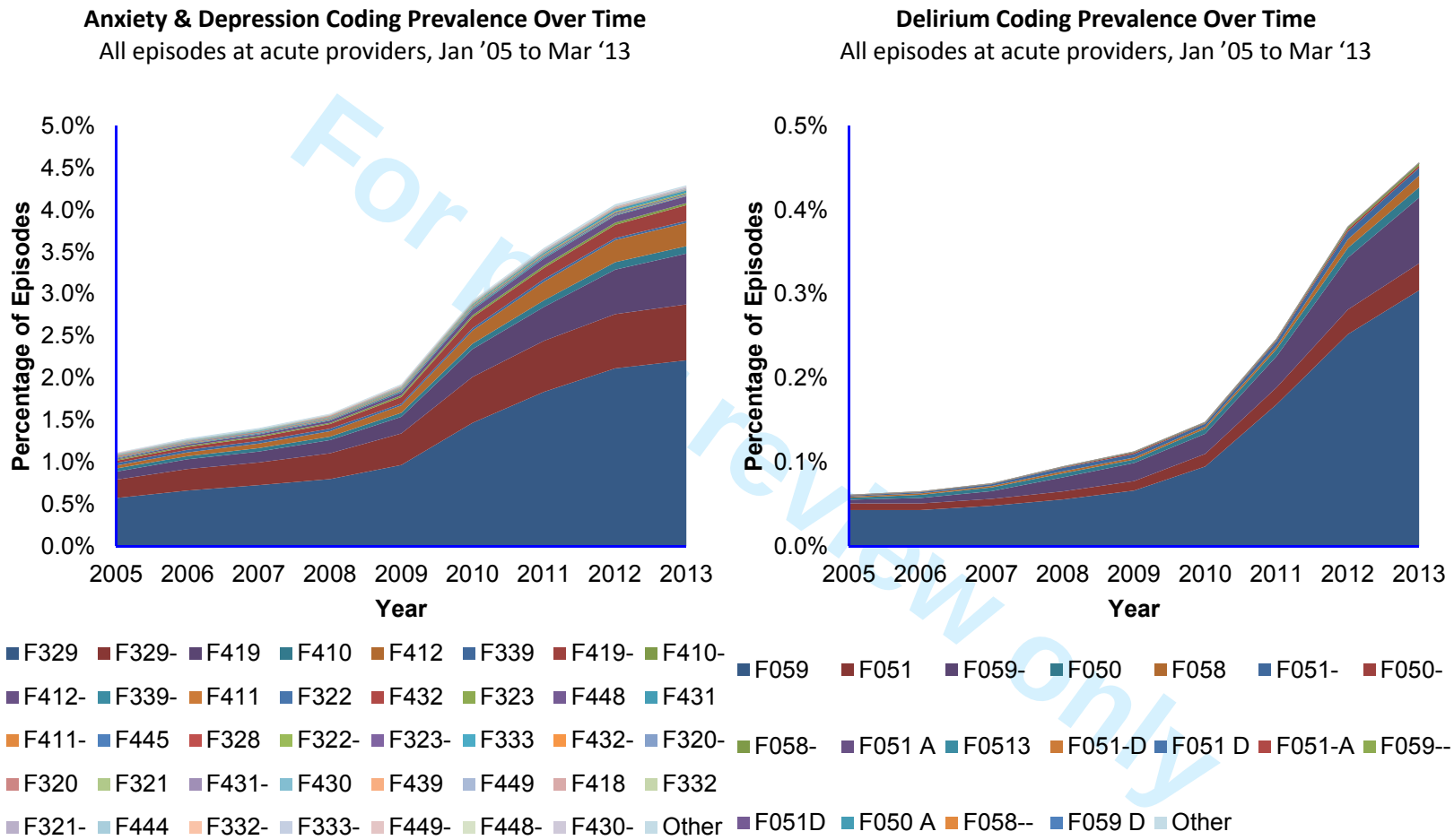
	W131A W132 W132- W1329 W133 W133- W1339 W134 W134- W1349 W135 W135- W136 W136- W1360 W137 W137- W138 W138- W1389 W138A W139 W139- W1390 W1392 W1393 W1399 W139A W140 W140- W140A W141 W141- W142 W142- W143 W143- W144 W144- W1449 W145 W145- W146 W146- W147 W147- W148 W148- W1482 W148A W149 W149- W1490 W1499 W149A W150 W150- W151 W151- W152 W152- W153 W153- W1530 W154 W154- W155 W156 W156- W157 W158 W158- W159 W159- W1590 W160 W160- W161 W161- W162 W162- W163 W163- W164 W164- W165 W165- W166 W166- W167 W167- W168 W168- W169 W169- W170 W170- W1700 W1701 W1708 W1709 W170A W171 W171- W172 W172- W1720 W1729 W172A W173 W173- W1730 W1739 W173A W174 W174- W1740 W1749 W174A W175 W175- W1752 W175A W176 W176- W1762 W1769 W176A W177 W177- W178 W178- W1780 W1781 W1782 W1789 W178A W179 W179- W1790 W1791 W1792 W1798 W1799 W179A W180 W180- W180-A W1800 W1801 W1802 W1803 W1804 W1808 W1809 W180A W180E W181 W181- W1810 W1811 W1819 W181A W181D W182 W182- W182-- W1820 W1821 W1822 W1828 W1829 W182A W183 W183- W1830 W1831 W1839 W183A W184 W184- W1840 W1848 W1849 W184A W185 W185- W1851 W1858 W1859 W185A W186 W186- W1869 W187 W187- W1879 W188 W188- W1880 W1881 W1882 W1883 W1888 W1889 W188A W189 W189- W1890 W1891 W1892 W1893 W1894 W1895 W1898 W1899 W189A W190 W190 AW190 DW190- W190-- W190-A W190-D W1900 W1901 W1903 W1905 W1908 W1909 W190A W191 W191- W191-A W1910 W1911 W1918 W1919 W191A W192 W192 DW192+ W192- W192-- W192-A W1921 W1922 W1928 W1929 W192A W193 W193- W1930 W1939 W194 W194* W194- W1940 W1941 W1943 W1948 W1949 W194A W195 W195- W1959 W195A W196 W196- W196A W197 W197- W197A W198 W198- W198-A W1980 W1981 W1982 W1988 W1989 W198A W199 W199 0 W199 DW199- W199-A W199-D W1990 W1991 W1992 W1993 W1994 W1995 W1996 W1998 W1999 W199A W199D W19X
Incontinence	R15X R15X A R15X D R15X- R15X-- R15X9 R32X R32X- R32X--

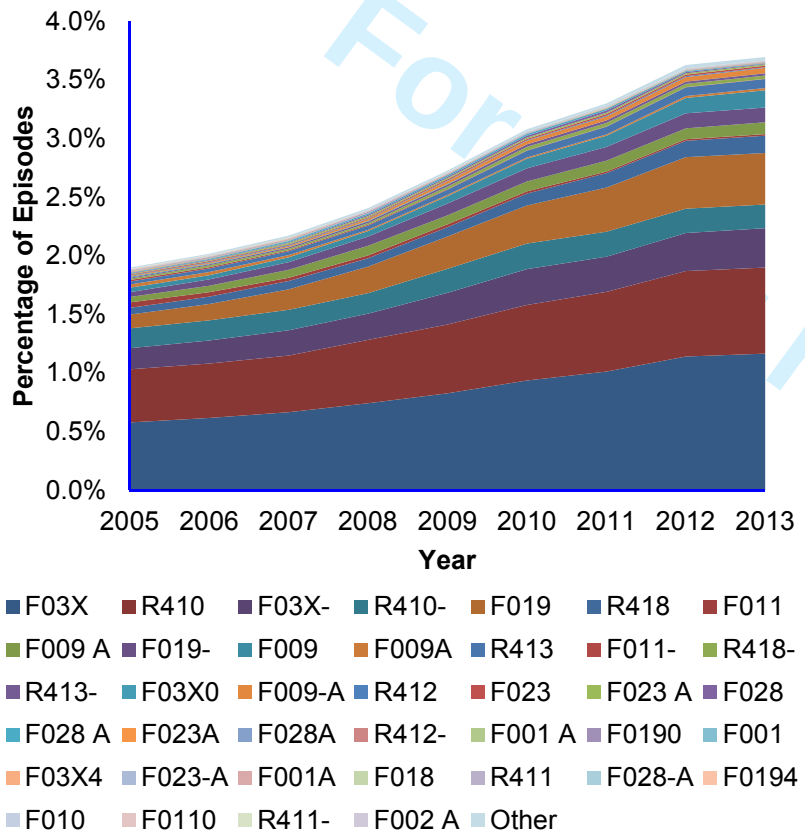
		R32X-A	R32X-D	R32X0	R32X1	R32X3	R32X9	R32XD	
Mobility problems	R260	R260-R2621	R260D R2623	R261 R263	R261-R263-	R261D R263D	R262 R268	R262 A R268-	R262-R268--
		R2683	R2686	R2689	R268D	R269	Z740	Z740 Z	Z740-
		Z740--	Z740-D	Z740.	Z7400	Z7401	Z7404	Z740C	Z740D
Pressure Ulcers	L890	L890-L892--	L890-- L893	L890D L893-	L891 L893-A	L891- L899	L891-- L899 A	L892 L899-	L892-L899--
		L89X	L89X -	L89X A	L89X D	L89X E	L89X I	L89X J	L89X Z
		L89X-	L89X--	L89X-D	L89X1	L89X5	L89X9	L89XD	
Senility	R54X	R54X A R54X9	R54X D R54XA	R54X- R54XD	R54X-D R54XI	R54X. R54XW	R54X0 R54XX	R54X6	R54X7

APPENDIX 2:



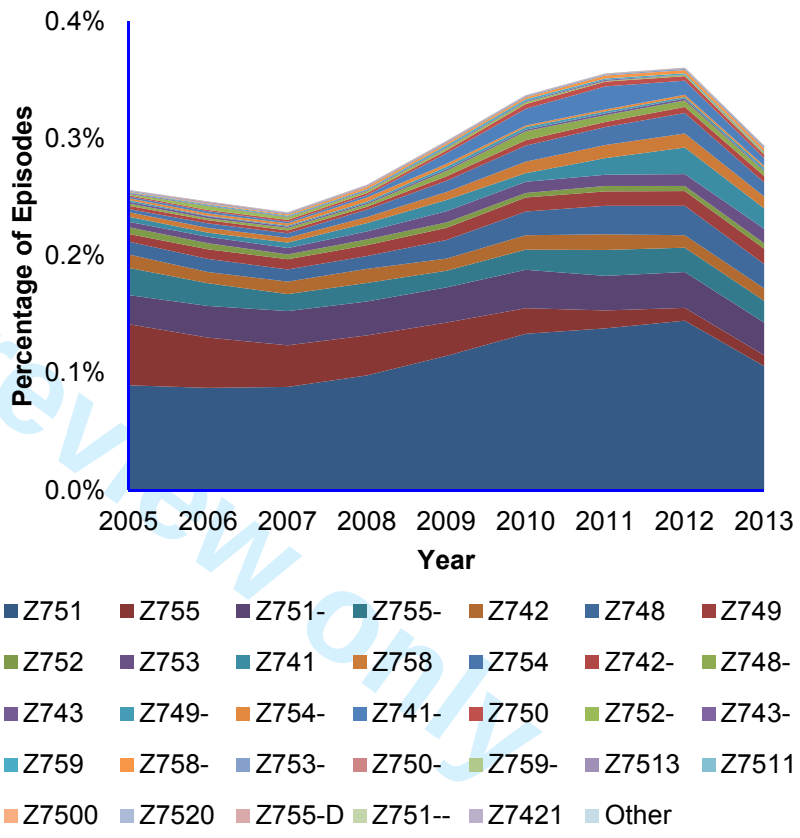
Dementia Coding Prevalence Over Time

All episodes at acute providers, Jan '05 to Mar '13



Functional Dependence Coding Prevalence Over Time

All episodes at acute providers, Jan '05 to Mar '13

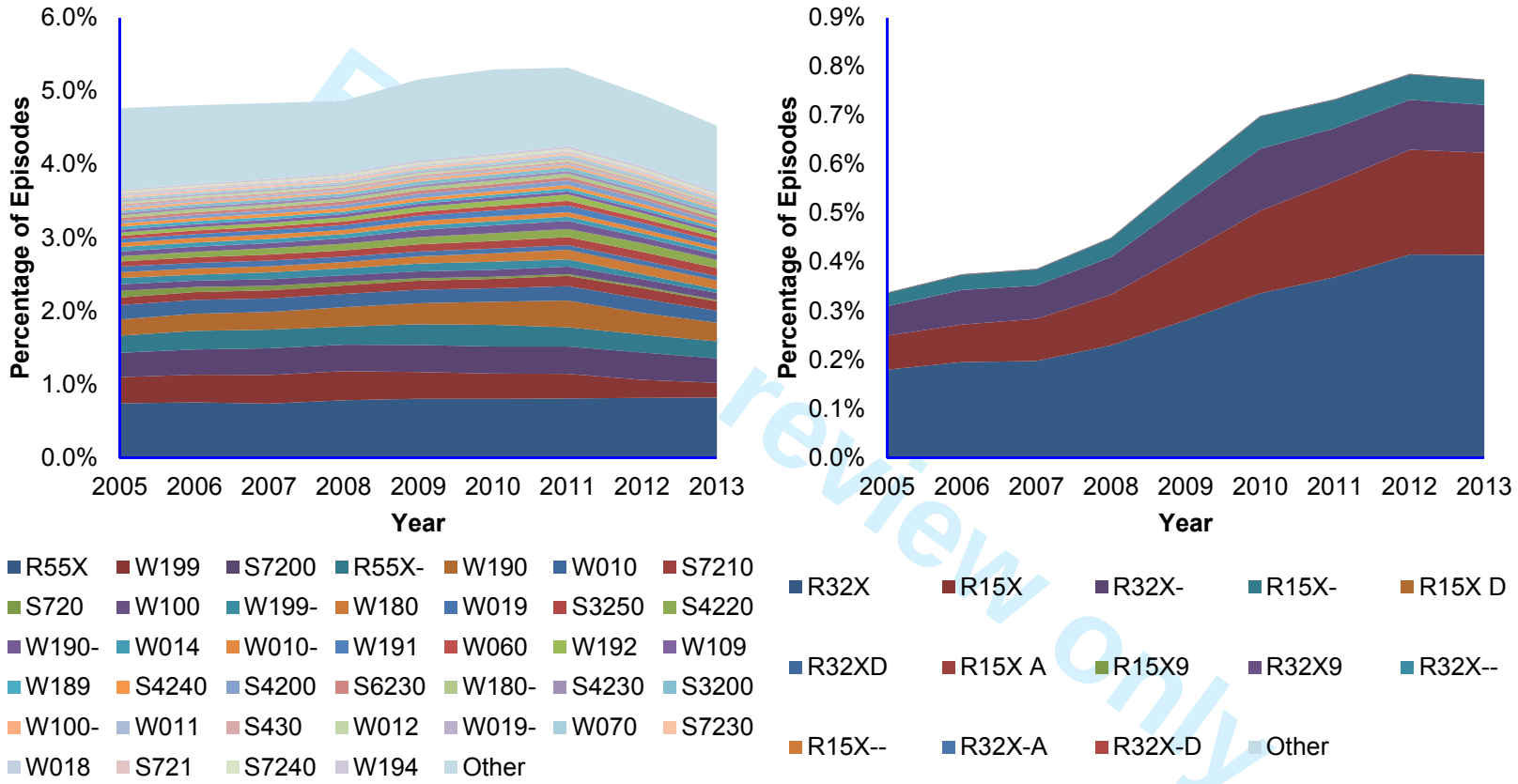


Falls (& significant fracture) Coding Prevalence Over Time

All episodes at acute providers, Jan '05 to Mar '13

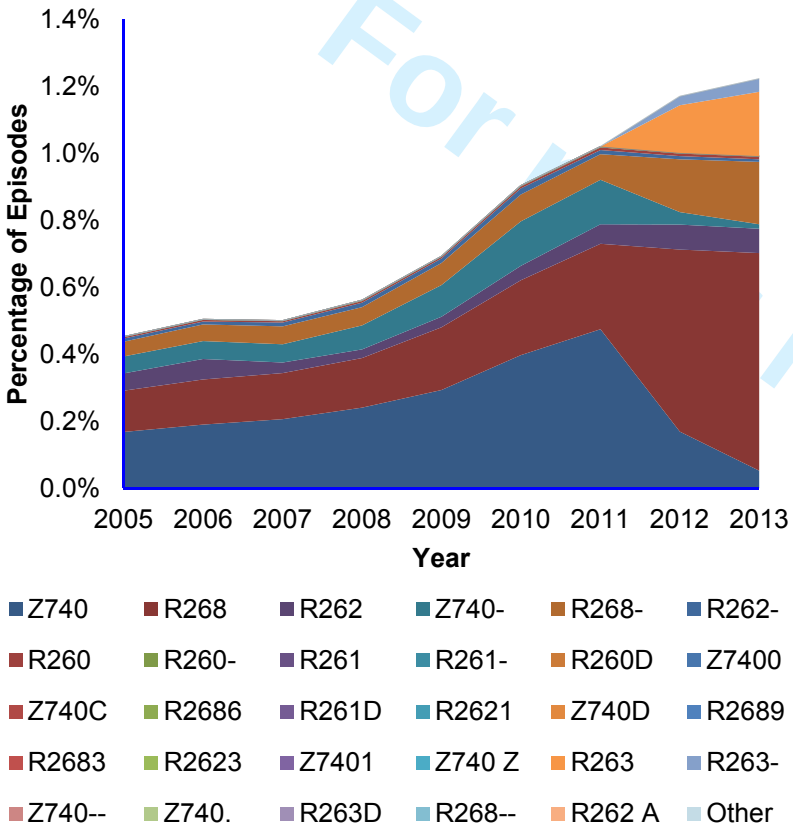
Incontinence Coding Prevalence Over Time

All episodes at acute providers, Jan '05 to Mar '13



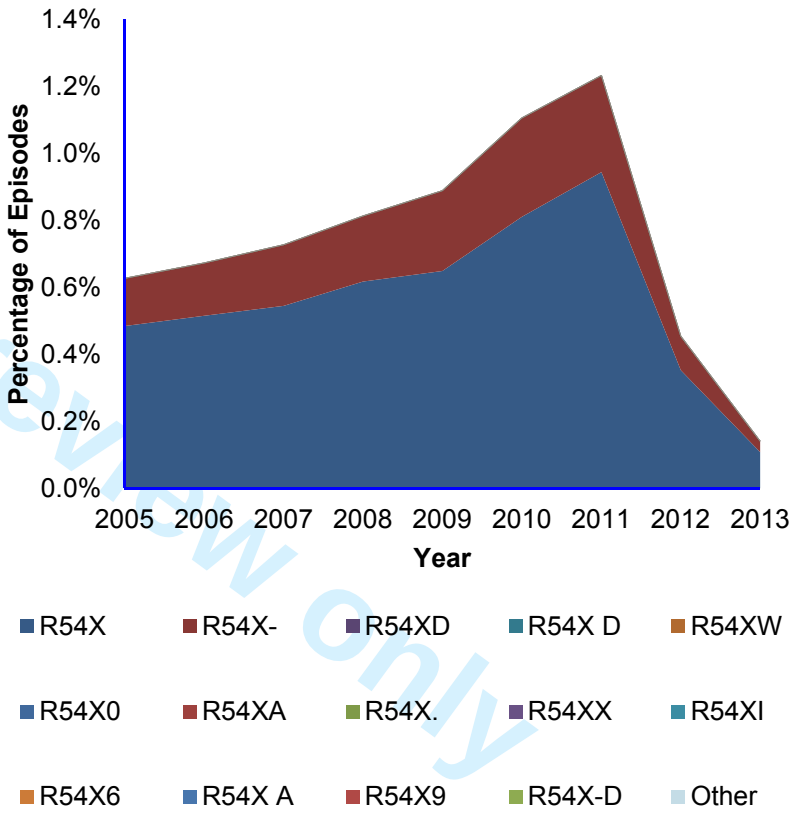
Mobility Problems Coding Prevalence Over Time

All episodes at acute providers, Jan '05 to Mar '13



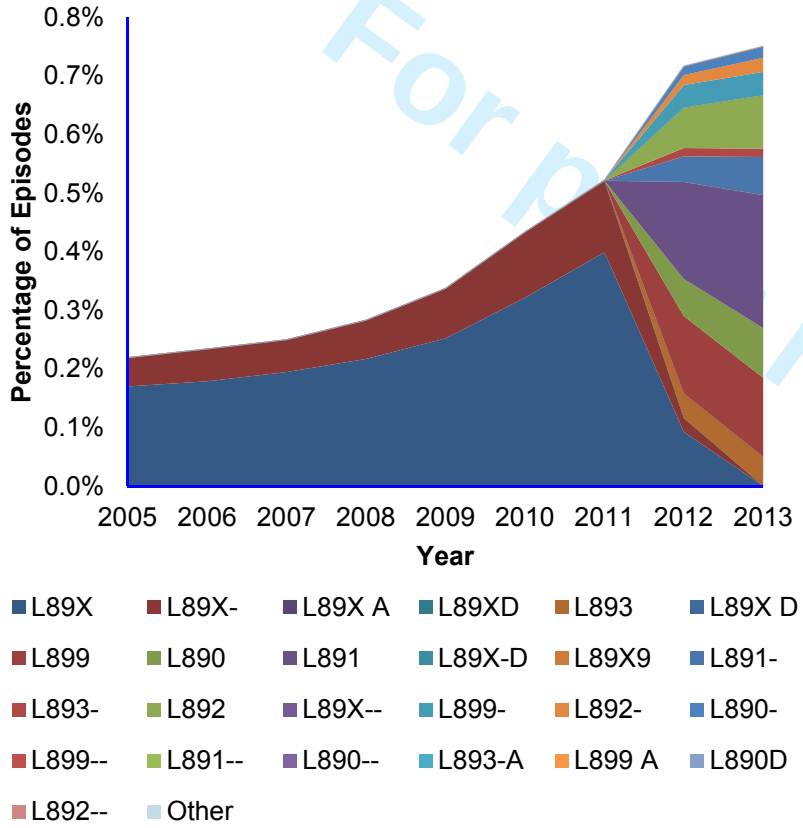
Senility Problems Coding Prevalence Over Time

All episodes at acute providers, Jan '05 to Mar '13



Pressure Ulcers Coding Prevalence Over Time

All episodes at acute providers, Jan '05 to Mar '13



STROBE 2007 (v4) checklist of items to be included in reports of observational studies in epidemiology*

Checklist for cohort, case-control, and cross-sectional studies (combined)

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Page 1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Page 2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Page 3
Objectives	3	State specific objectives, including any pre-specified hypotheses	Page 3
Methods			
Study design	4	Present key elements of study design early in the paper	Pages 3-7
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Page 4
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	Page 4
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Page 4-7, Appendix 1
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Page 5-6, Appendix 1
Bias	9	Describe any efforts to address potential sources of bias	Page 4, Page 18
Study size	10	Explain how the study size was arrived at	Page 4, Page 7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Page 4, Page 7
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	Page 7
		(*b*) Describe any methods used to examine subgroups and interactions	Page 7
		(*c*) Explain how missing data were addressed	Page 7
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed	N/A

		Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	Page 7
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Page 4, Page 7
		(b) Give reasons for non-participation at each stage	N/A
		(c) Consider use of a flow diagram	N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	N/A
		(b) Indicate number of participants with missing data for each variable of interest	Page 7
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	N/A
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	N/A
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	N/A
		Cross-sectional study—Report numbers of outcome events or summary measures	Page 7-14
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Page 7, Page 9-14
		(*b*) Report category boundaries when continuous variables were categorized	N/A
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Page 8, Page 10
Discussion			
Key results	18	Summarise key results with reference to study objectives	Page 16-17
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 18
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Pages 15-18
Generalisability	21	Discuss the generalisability (external validity) of the study results	Pages 15-18
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Page 21

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.
Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

Correction

Soong J, Poots AJ, Scott S, *et al*. Developing and validating a risk prediction model for acute care based on frailty syndromes. *BMJ Open* 2015;**5**:e008457. The corresponding author's email address is incorrect in this paper. The correct address is j.soong@imperial.ac.uk

BMJ Open 2015;**5**:e008457corr1. doi:10.1136/bmjopen-2015-008457corr1