Accepted Article

Journal of Frailty, Sarcopenia and Falls

Original Article

Modified Hospital Frailty Risk Score (mHFRS) as a Tool to Identify and Predict Outcomes for Hospitalised Older Adults at Risk of Frailty

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Abstract

Objectives: This study aims to determine whether modified Hospital Frailty Risk Score (mHFRS) can identify frail hospitalised older adults by comparing mHFRS to HFRS and Clinical Frailty Scale (CFS). **Methods**: A retrospective review was undertaken in patients =>65 years hospitalised following an Emergency Department attendance between 1st July 2022 and 31st March 2023. Predictive models were evaluated with correlation and measure of agreement between frailty risk scores, CFS and HFRS, CFS and modified HFRS (mHFRS) using the Spearman's rank correlation and Cohen's kappa (κ). **Results**: Of 3042 patients, CFS categorised 1635 (53.7%) patients as non-frail (CFS 1-4) and 1407 (46.3%) as frail (CFS 5-9,p<0.001). Frail patients were more likely to be female (55.9%), older (81.8 years, SD 8.41 vs 75.3 years, SD 7.20, p<0.001), with longer LOS (52.5% % vs 31.5%, p<0.001), higher 30-day emergency re-admission (18.5% vs 9.9%, p<0.001) and higher mortality at all time points. We could compute mHFRS for 1623 (53.4%) patients, of whom, 37.5% were low risk, 40.5% intermediate risk and 22.1% high frailty risk. mHFRS showed significant correlation with CFS (p<0.001) and HFRS (p<0.001), respectively and achieved comparable association with clinical outcomes. **Conclusion**: mHFRS was better at identifying non-frail patients and provides a novel, standardised and comparable frailty risk stratification tool for screening older hospitalised patients.

Keywords: Clinical Frailty Scale, Frailty, Geriatrics, Hospital Frailty Risk Score

Introduction

Frailty is defined as a syndrome with multiple causes and contributors that is characterized by diminished strength, endurance, and reduced physiologic function that increases an individual's vulnerability for developing increased dependency and/or death[1]. Frailty can be prevented, reversed, or delayed in the early stages and managed in the later stages, through early detection and interventions to optimize functional ability, activity participation and quality of life[2]. The future aging demographic will result in higher proportions of people aged 60 and above, who will make up 40% of Singapore's population by 2050[3] and thus the number of frail older adults will rise[4]. One likely consequence is that more frail patients will attend hospital[3,5] and the ability to provide frailty risk stratification and appropriately direct resources may help to improve patient outcomes[6,7].

The need for a standard assessment tool to identify frailty has been highlighted in the Asia-Pacific Clinical Practice guidelines for management of frailty[8] and Clinical

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Edited by: *Jagadish K. Chhetri*

Accepted *9 August 2024*

Frailty Scale (CFS) is Singapore's nationally agreed frailty community screening tool[2]. While the CFS is a relatively quick and simple tool to use[9], it requires time to administer, has a training cost, and is operator-dependent. To illustrate, a study in the Emergency Department (ED) setting has shown significant missing CFS scores in manual data collection with up to 50% of patients not scored[10]. The use of CFS has also been critiqued to be susceptible to an inherent "ableism" bias since CFS is heavily weighted on patient function, for example, a patient with a congenital or traumatic amputation may have very different baseline health status compared to a patient with an amputation due to worsening control of chronic diabetes but both patients will receive similar score on CFS[11]. Another assessment of CFS has echoed the disproportionate reliance on physical mobility as an indicator of physiologic reserve[12].

An alternative low-cost tool is the Hospital Frailty Risk Score (HFRS)[13] which uses the International Statistical Classification of Diseases and Related Health Problem, Tenth Revision (ICD-10) diagnostic codes, which are routinely collected in many health information systems. Unlike the CFS, the HFRS does not require a clinical assessment, and removes inter-operability variation and reduces the assessor burden associated with the CFS. HFRS has been shown to identify patients at higher risk of longer hospital length of stay (LOS), higher 30-day readmissions and increased 30-day mortality in a variety of medical[14-16] and surgical[17-20] patients. HFRS has also been validated against two widely used clinical frailty tools which include the Fried phenotype and Rockwood Frailty Index[21]. HFRS has been validated in variety of clinical settings and in several countries across the world[14,22-24] but there is a role for a risk stratification tool that is easy to implement and use alongside standard clinical frailty assessment tools.

HFRS has been used as population-based quality improvement tool and one of the limitations of HFRS is that ICD coding typically takes 6-8 weeks from the incident admission, meaning the HFRS can only be used retrospectively and does not allow access to frailty risk during an incident admission. The aim of this study was to develop a modified HFRS to identify patients who would benefit from frailty assessment and interventions during their acute hospitalisation, at the point of admission. This method is a modification on the standard HFRS methodology, and considers the ICD-10 codes of previous admissions, without the index admission. Although we expect some loss of sensitivity compared to the standard HFRS due to the exclusion of information from the index admission, the advantage of the mHFRS over the HFRS is that the mHFRS can be visible to clinicians during the patients hospital admission, and allow frailty interventions to be delivered in a timely fashion. A further aim is to compare the efficacy of a modified HFRS (mHFRS) to both the standard HFRS methodology and to CFS, by determining whether these tools alone or in combination, can reliably identify those at risk of frailty during hospitalisation. We anticipate that the mHFRS will be less sensitive than a face-face screening tool such as CFS, but may be a sensitive tool that is more clinically applicable as a frailty risk stratification tool than the population based standard HFRS.

Primary & Secondary Aims

Primary aim: to develop and investigate the potential future use of a modified Hospital Frailty Risk Score (mHFRS) to identify frail older patients during their acute hospitalisation.

Secondary aim: to compare the efficacy of a mHFRS to the standard HFRS methodology and to the CFS, to determine whether these tools are reliable at identifying frailty during hospitalisation.

Materials and Methods

Study design, data collection, statistical analysis, and oversight

The study involved a retrospective review of electronic health records undertaken in older patients (age 65 years and above) attending the Emergency Department (ED) from 1st July 2022 through to 31st March 2023 and hospitalised after being triaged at the ED. Only Singaporean citizens and Singapore Residents (permanent residents and long-term pass holders) were included in the data collection. The analysis excluded patients discharged home from the ED, discharges from the Short Stay Unit and elective admissions. Demographic data collection included age, sex and race, and Body Mass Index (BMI) was included if available within the 12 months prior to admission. In those with no BMI available within the previous 12 months, imputation was performed to replace missing values with the median BMI of each age group (65-74, 75-84, 85-94, >=95) to avoid skewing data due to outliers[25]. Sensitivity analyses undertaken in previous work had shown this method of imputation yielded similar results compared to multivariate regression using the sample mean. Charlson Co-morbidity Index (CCI) was used to assessed co-morbidity[26] and was calculated retrospectively based on the discharge diagnoses from the index admission, and coded by the World Health Organization (WHO) International Classification of Diseases (ICD-10)[27].

Outcomes derived from hospitalisation data included length of stay (LOS), defined as =>6 days hospitalised, 30-day emergency re-admissions, in-patient mortality, and mortality at 30-days, and 90-days from the date of admission. Analysis of 30-day readmissions excluded those who died during hospitalisation. CFS was derived from triage data at the patient's first ED attendance during the study period. CFS is a widely used judgement-based tool to screen for frailty that will broadly stratify degrees of fitness and frailty and should reflect the patient's function two weeks before hospital admission. CFS 1-4 were analysed as non-frail and CFS =>5 as frail

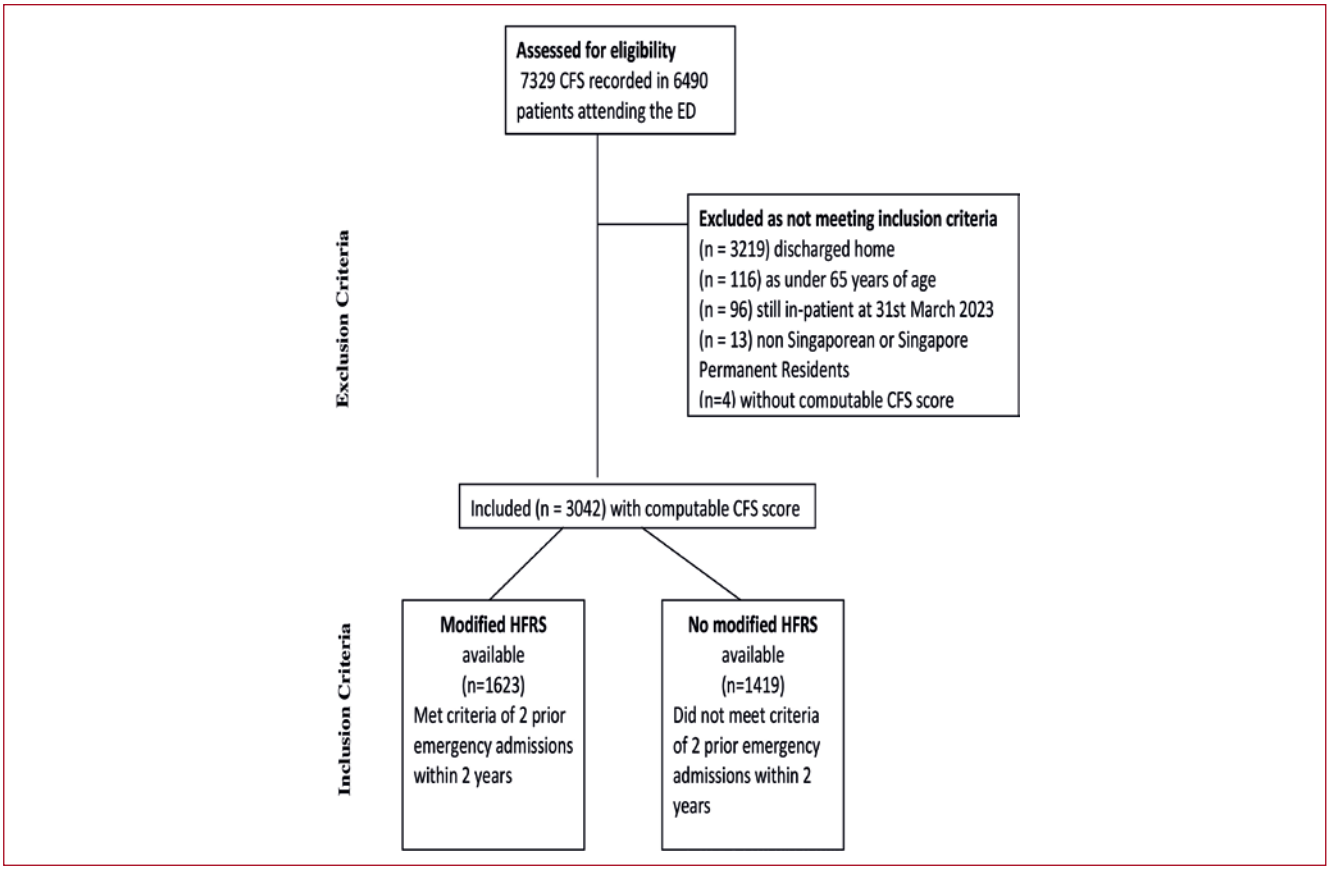

Figure 1. Flow chart showing numbers of patients with CFS, HFRS and mHFRS available.

for baseline characteristics. For model performance CFS was grouped with 1-4 as non-frail, 5-6 as frail and 7-9 as severely frail.

HFRS was calculated using the primary and secondary diagnoses during the incident (current) hospitalisation and the prior 2 emergency hospital admissions (if any) within the preceding 2 years for each patient, based on the 109 three-character ICD-10-CM codes (21). Each ICD-10 code is associated with a frailty weight, and the HFRS is computed cumulatively by summing the weight of each ICD-10 code. (28). Supplementary Information 1 shows the 109 ICD codes used to calculate HFRS[21]. Individuals were categorized into 3 frailty risk groups, low [<5], intermediate [5-15], and high risk [>15] of frailty according to their calculated HFRS and based on previously validated cut off points [20]. This methodology does not allow scoring of frailty risk during hospitalisation, as the index admission typically takes 6-8 weeks to be coded and hence the standard HFRS can only be used retrospectively.

To test the possibility of utilising the HFRS as a frailty risk screening tool, we utilised a modified version of the HFRS, named the modified HFRS (mHFRS) which has not previously been described. The mHFRS was calculated without the index admission and categorised patients into high [>15], intermediate [5-15] and low risk [<5] of frailty whilst retaining information acquired from 2 prior emergency admissions within 2 years of the incident hospital admission date. Of those with no prior emergency admission within the last 2 years, CFS indicated that almost 70% of them were not frail (CFS<4), hence these patients were assigned as mHFRS 0 and categorized as low risk of frailty for the purpose of predictive modelling.

To achieve the study aims, we compared agreement between the following frailty scores:

1) CFS vs. HFRS (HFRS standard methodology, index admission & previous 2 emergency admissions in 2 years).
2) CFS vs. mHFRS (previous 2 emergency admissions in 2 years).

We undertook a predictive analysis to evaluate how well the frailty measures, CFS, HFRS and mHFRS, could correctly predict adverse outcomes such as long LOS, 30-day emergency re-admissions and mortality.

	CFS <=4 (N=1635)	CFS >4 (N=1407)	Overall (N=3042)	p-value
Age (SD)	75.3 (7.20)	81.8 (8.41)	78.3 (8.43)	<0.001
Female	742 (45.4%)	786 (55.9%)	1528 (50.2%)	<0.001
Race				
Chinese	1133 (69.3%)	999 (71.0%)	2132 (70.1%)	0.648
Indian	106 (6.5%)	78 (5.5%)	184 (6.0%)	
Malay	261 (16.0%)	216 (15.4%)	477 (15.7%)	
Other Races	135 (8.3%)	114 (8.1%)	249 (8.2%)	
CCI Category				
0	644 (39.4%)	361 (25.7%)	1005 (33.0%)	<0.001
1 to 2	537 (32.8%)	472 (33.5%)	1009 (33.2%)	
3 to 4	324 (19.8%)	382 (27.2%)	706 (23.2%)	
>4	130 (8.0%)	192 (13.6%)	322 (10.6%)	
HFRS Risk				
Low Risk	936 (57.2%)	258 (18.3%)	1194 (39.3%)	<0.001
Intermediate Risk	515 (31.5%)	556 (39.5%)	1071 (35.2%)	
High Risk	184 (11.3%)	593 (42.1%)	777 (25.5%)	
Modified HFRS Risk				
Low Risk	377 (23.1%)	231 (16.4%)	608 (20.0%)	<0.001
Intermediate Risk	244 (14.9%)	413 (29.4%)	657 (21.6%)	
High Risk	56 (3.4%)	302 (21.5%)	358 (11.8%)	
No prior admission (No Score)	958 (58.6%)	461 (32.8%)	1419 (46.6%)*	
Total	1635 (100.0%)	1407 (100.0%)	3042 (100.0%)	

*Abbreviation: CFS, Clinical Frailty Scale; CCI, Charlson Comorbidity Index; HFRS, Hospital Frailty Risk Score; SD, Standard Deviation. *Percentages may not sum to 100% due to rounding.*

Table 1. Baseline Characteristics.

Data Extraction and Statistical analysis

A third-party de-identification process was taken to render the database non-identifiable for research. This process was undertaken by the Data Management and Informatics team at Changi General Hospital. No IRB approval was needed for the use of this data. The Health Systems Intelligence team subsequently analysed the anonymised data using Python (v3.6.4; Python Software Foundation) and R statistical software (v3.6.1; R Core Team 2019). Python was used for data pre-processing, while R was used for statistical analysis. The baseline characteristics were analysed and stratified by CFS, where continuous variables are presented as means and standard deviations (SD), while categorical variables are presented as counts and percentages. HFRS was analysed as a categorical variable (high, intermediate, low risk). To assess the association of the CFS categories with various variables and outcomes for statistical significance, we conducted the Pearson χ^2 test, Analysis of Variance (ANOVA), and Kruskal-Wallis test as appropriate.

The correlation and the measure of agreement between CFS and HFRS, CFS and mHFRS respectively, were assessed using the Spearman's rank correlation and Cohen's kappa (κ). Cohen's kappa is interpreted as follows: 0.01-0.20 as none to slight, 0.21-0.40 as fair, 0.41-0.60 as moderate, 0.61-0.80 as substantial, and 0.81-1.00 as almost perfect agreement[29]. Mcnemer's test was applied to compare for significant differences in the performance of the frailty scores in the binary classification tasks. An adjusted logistic regression model was used where dataset was randomly split with 80% used to train the model and 20% to validate the model[30]. The variables age and BMI were log-transformed to adjust for nonlinearity[31]. The frailty scores and CCI were included in the adjusted logistic regression model as categorical predictors. The AUC ROC was used to assess model discrimination. All statistical analyses were performed using a two-tailed test with a significance level of $p<0.05$.

	CFS <=4 (N=1635)	CFS >4 (N=1407)	Overall (N=3042)	p-value
LOS >=6	515 (31.5%)	738 (52.5%)	1253 (41.2%)	<0.001
Inpatient Mortality	32 (2.0%)	86 (6.1%)	118 (3.9%)	<0.001
30 day Mortality	37 (2.3%)	128 (9.1%)	165 (5.4%)	<0.001
90 day Mortality	84 (5.1%)	222 (15.8%)	306 (10.1%)	<0.001
30 day Re-admission (emergency)*	162 (9.9%)	260 (18.5%)	422 (13.9%)	<0.001

*Abbreviations: CFS, Clinical Frailty Scale; LOS, Length of Stay. *excludes cases who died inpatient.*

Table 2. Outcomes.

A. Standard HFRS:				
		HFRS group, n (%)		
		Low (<5)	Intermediate (5-15)	High (>15)
CFS group	Non-Frail (n = 1635)	936 (57.2)	515 (31.5)	184 (11.3)
	Frail (n = 1064)	226 (21.2)	434 (40.8)	404 (38.0)
	Severely Frail (n = 343)	32 (9.3)	122 (35.6)	189 (55.1)

CFS group – Non-Frail: 1 to 4; Frail: 5 & 6; Severely Frail: 7 to 9; HFRS group – Low: <5; Intermediate: 5-15; High: >15. Abbreviations: CFS, Clinical Frailty Scale; HFRS, Hospital Frailty Risk Score.

B. Modified HFRS:				
		Modified HFRS group, n (%)		
		Low (<5)	Intermediate (5-15)	High (>15)
CFS group	Non-Frail (n = 1635)	1335 (81.7)	244 (14.9)	56 (3.4)
	Frail (n = 1064)	565 (53.1)	315 (29.6)	184 (17.3)
	Severely Frail (n = 343)	127 (37.0)	98 (28.6)	118 (34.4)

CFS group – Non-Frail: 1 to 4; Frail: 5 & 6; Severely Frail: 7 to 9; HFRS group – Low: <5; Intermediate: 5-15; High: >15. Abbreviations: CFS, Clinical Frailty Scale; Modified HFRS, Modified Hospital Frailty Risk Score.

Table 3.: Cross-Tabulation of the CFS and HFRS frailty groups.

Results

Baseline characteristics

A total of 3042 patients were included in the study (Figure 1: Flow diagram). Average age was 78.3 years (SD 8.43), and using CFS, 1635 patients (53.7%) were categorised as non-frail (CFS 1-4) and 1407 patients (46.3%) were categorised as frail (CFS 5-9) (Table 1). Standard HFRS methodology identified 3042 patients, of whom 1194 (39.3%) were low risk, 1071 (35.2%) were intermediate risk and 777 (25.5%) were high risk of frailty (Table 1). There were 1419 patients (46.6%) with no prior admission, hence no mHFRS, of which 67.5% were CFS <4 and 32.5% were CFS >4. However, 1623 patients had prior hospitalisation with ascertained mHFRS and of these, 608 (37.5%) were low risk, 657 (40.5%) were intermediate risk and 358 (22.1%) were high risk of frailty (Table 1). Comparing the baseline characteristics of the 1407 (46.3%) of patients identified as frail using CFS >4, HFRS vs mHFRS identified 18.3% vs 16.4% of them as low risk, 39.5% vs 29.4% as intermediate risk and 42.1% vs 21.5% as high risk of frailty. The remaining 32.8% could not be categorised using mHFRS as they did not have any prior admissions within the preceding 2 years (Table 1). Conversely, those identified as not frail (CFS <4), HFRS vs mHFRS identified 57.2% vs 23.1% of them as low risk, 31.5% vs 14.9% as intermediate risk and 11.3% vs 3.4% as high risk of frailty. Similarly. 58.6% of these patients could not be categorised using mHFRS (Table 2).

Frail patients were older (81.8 years, SD 8.41 vs 75.3 years SD 7.20, p<0.001) and there were more females in the frail cohort (55.9% vs 45.4% p<0.001) (Table 1). There were no significant differences in race across the whole group, which was broadly representative of Singapore's demographics with 70.1% Chinese, 15.7% Malay, 6.0%

	CFS vs HFRS	CFS vs mHFRS
Precision	51.2%	58.1%
Sensitivity	51.2%	58.1%
Specificity	75.6%	79.1%
Micro-F1	0.512	0.581
Macro-F1	0.469	0.477
Balanced accuracy	0.510	0.486
Cohen's kappa	0.235	0.243
Mcnemer's test	<0.001	<0.001
Spearman's correlation coefficient	0.511	0.402

Abbreviations: CFS, Clinical Frailty Scale; HFRS, Hospital Frailty Risk Score; mHFRS, modified Hospital Frailty Risk Score.

Table 4. Comparison of agreement of CFS vs HFRS and CFS vs mHFRS.

Indian and 8.2% other races (Table 1). CCI was significantly different across frail vs non frail groups for all categories, 25.7% vs 39.4% for CCI 0, 33.5% vs 32.8% for CCI 1-2, 27.2% vs 19.8% for CCI 3-4 and 13.6% vs 8.0% for CCI >4, p<0.001 (Table 1).

Hospitalisation Usage and Mortality

Patients classified as frail using CFS had significantly longer LOS defined as => 6 days (52.5% vs 31.5%, p<0.001) (Table 2), and higher 30-day emergency hospital re-admissions (18.5% vs 9.9%, p<0.001) (Table 2) compared to non-frail patients. In-patient (6.1% vs 2.0%, p<0.001), 30-day (9.1% vs 2.3%, p<0.001) and 90-day mortality (15.8% vs 5.1%, p<0.001) (Table 2) were all higher for patients classified as frail using CFS.

Model Comparison

To determine how accurately the two frailty risk scores (HFRS and mHFRS) could identify frail patients, CFS was categorised into 3 groups, non-frail (CFS 1-4), frail (CFS 5 & 6) and severely frail (CFS 7-9). Table 3 depicts the cross tabulation of the CFS with HFRS and mHFRS. Of those that CFS identified as non-frail patients, 57.2% vs 81.7% were similarly identified by HFRS and mHFRS respectively (Table 3). While 40.8% vs 29.6% of frail patients and 55.1% vs 34.4% of severely frail patients were identified by HFRS and mHFRS respectively (Table 3). mHFRS was better at identification of non-frail patients 81.7% vs 57.2%, identified by HFRS but the mHFRS performed poorer compared to the standard HFRS with 55.1% vs 34.4% identified as severely frail and 40.8% vs 29.6% identified as frail patients. Overall, the mHFRS had better sensitivity

Table 5. Univariate logistic regression for potential covariates.

Outcomes		OR (95% CI), *p-value*				
		Length of Stay (LOS >=6 days)	30 day Emergency Readmissions	Inpatient Mortality	30 d Mortality	90 d Mortality
Age		1.03 (1.03-1.04) *<0.001*	1.02 (1.01-1.03) *<0.001*	1.04 (1.02-1.06) *<0.001*	1.05 (1.03-1.06) *<0.001*	1.04 (1.03-1.06) *<0.001*
Gender	Male	Reference	Reference	Reference	Reference	Reference
	Female	1.32 (1.15-1.53) *<0.001*	0.81 (0.66-1.00) *<0.050*	0.83 (0.57-1.20) *0.323*	0.95 (0.70-1.31) *0.763*	0.92 (0.73-1.17) *0.492*
BMI		0.99 (0.98 – 0.99) *<0.001*	0.99 (0.99 – 1.00) *<0.050*	0.99 (0.98 – 1.00) *<0.001*	0.99 (0.98 – 1.00) *<0.010*	0.99 (0.98 – 0.99) *<0.001*
CCI	0	Reference	Reference	Reference	Reference	Reference
	1-2	1.73 (1.44-2.08) *<0.001*	1.88 (1.41-2.51) *<0.001*	1.41 (0.79-2.54) *0.250*	2.04 (1.24-3.45) *<0.010*	2.06 (1.41-3.04) *<0.001*
	3-4	2.18 (1.78-2.67) *<0.001*	2.77 (2.07-3.74) *<0.001*	2.57 (1.49-4.56) *<0.001*	2.70 (1.62-4.60) *<0.001*	3.18 (2.18-4.70) *<0.001*
	>=5	4.79 (3.68-6.29) *<0.001*	3.03 (2.11-4.35) *<0.001*	6.01 (3.45-10.74) *<0.001*	8.60 (5.25-14.53) *<0.001*	9.60 (6.54-14.31) *<0.001*

Abbreviations: BMI, Body Mass Index; CCI, Charlson Comorbidity Index; OR, Odds Ratio.

Outcome		Adjusted* OR [aOR] (95% CI) p-value				
		Length of Stay (LOS >=6 days)	30 day Emergency Readmissions	Inpatient Mortality	30 day Mortality	90 day Mortality
CFS	Non-Frail	1.00	1.00	1.00	1.00	1.00
	Frail	1.80 (1.48-2.19) *<0.001*	1.67 (1.26-2.21) *<0.001*	1.47 (0.85-2.55) *0.169*	1.91 (1.17-3.15) *<0.050*	1.78 (1.25-2.53) *<0.010*
	Severely Frail	1.83 (1.38-2.45) *<0.001*	3.14 (2.19-4.46) *<0.001*	4.54 (2.53-8.20) *<0.001*	6.28 (3.72-10.76) *<0.001*	5.09 (3.41-7.63) *<0.001*
HFRS	Low (<5)	1.00	1.00	1.00	1.00	1.00
	Intermediate (5-15)	3.24 (2.61-4.04) *<0.001*	1.61 (1.19-2.19) *<0.010*	3.80 (1.88-8.56) *<0.001*	3.25 (1.78-6.37) *<0.001*	2.78 (1.81-4.39) *<0.001*
	High (>15)	6.38 (4.96-8.26) *<0.001*	2.08 (1.48-2.94) *<0.001*	4.62 (2.20-10.67) *<0.001*	3.85 (2.05-7.72) *<0.001*	3.51 (2.24-5.64) *<0.001*
mHFRS	Low (<5)	1.00	1.00	1.00	1.00	1.00
	Intermediate (5-15)	1.24 (1.00-1.53) *<0.050*	1.79 (1.34-2.36) *<0.001*	1.04 (0.61-1.70) *0.895*	1.33 (0.84-2.06) *0.212*	1.43 (1.02-1.99) *<0.050*
	High (>15)	1.31 (0.99-1.72) *0.057*	2.50 (1.77-3.50) *<0.001*	1.02 (0.54-1.85) *0.941*	1.67 (1.01-2.72) *<0.050*	1.78 (1.21-2.60) *<0.010*

**Models adjusted for patient's age, gender, body mass index and Charlson Comorbidity group. Abbreviations: CCI, Charlson Comorbidity Index; CFS, Clinical Frailty Scale; HFRS, Hospital Frailty Risk Score; mHFRS, modified Hospital Frailty Risk Score; Adjusted OR, Adjusted Odds Ratio.*

Table 6. Association between frailty metrics and clinical outcomes.

Table 4 depicts the overall model metrics to allow for comparison of agreement of the CFS vs HFRS and CFS vs mHFRS. There was fair agreement using Cohens's kappa, which showed similar agreement across the frailty comparators, κ of 0.235 and 0.243 for HFRS and mHFRS respectively (Table 4).

Baseline Covariates and Outcomes

The univariate logistic regression analysis shows age, gender, BMI, and CCI to be significant predictors for LOS>= 6 days and 30-day emergency readmission, respectively (Table 5). The predictors age, BMI, CCI 3-4 and CCI >=5 were shown to be significantly associated with inpatient mortality, 30-day mortality and 90-day mortality. CCI 1-2 group was also a significant predictor for 30-day mortality and 90-day mortality respectively.

Predictive Modelling and Discriminative Performance for Adverse Outcomes

In the adjusted logistic regression model, CFS, HFRS and mHFRS are significant predictors of 30-day readmission (Table 6). Figures 2-6 and Table 7 show the AUC ROC curves and the summary of the adjusted AUC ROC prediction

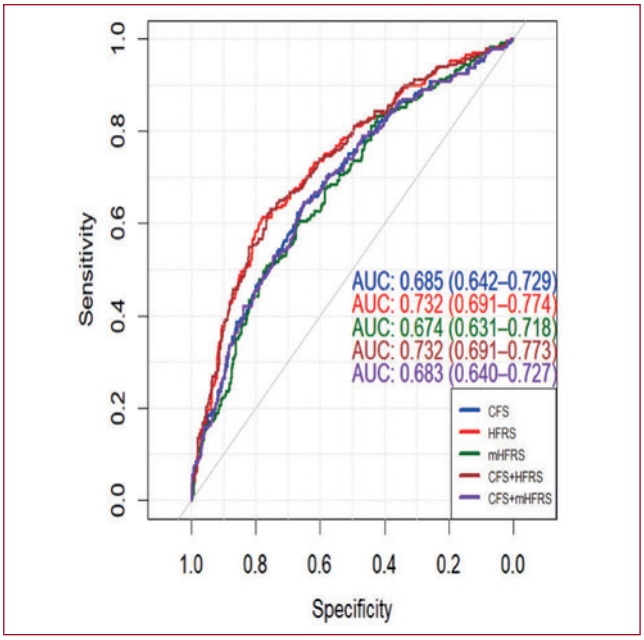

Figure 2. AUC ROC for Length of Stay (LOS>=6 days) showed similar performance for HFRS and CFS + HFRS, better than CFS alone; similar performance for mHFRS, CFS and CFS + mHFRS.

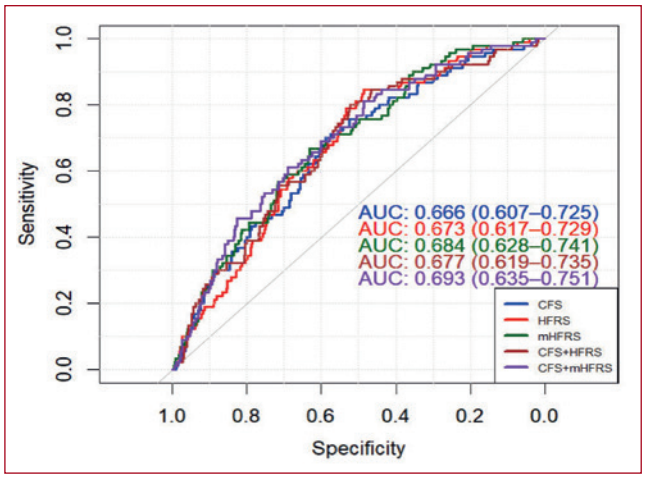

Figure 3. AUC ROC for 30 day emergency readmissions showed mHFRS performs slightly better than CFS and HFRS alone.

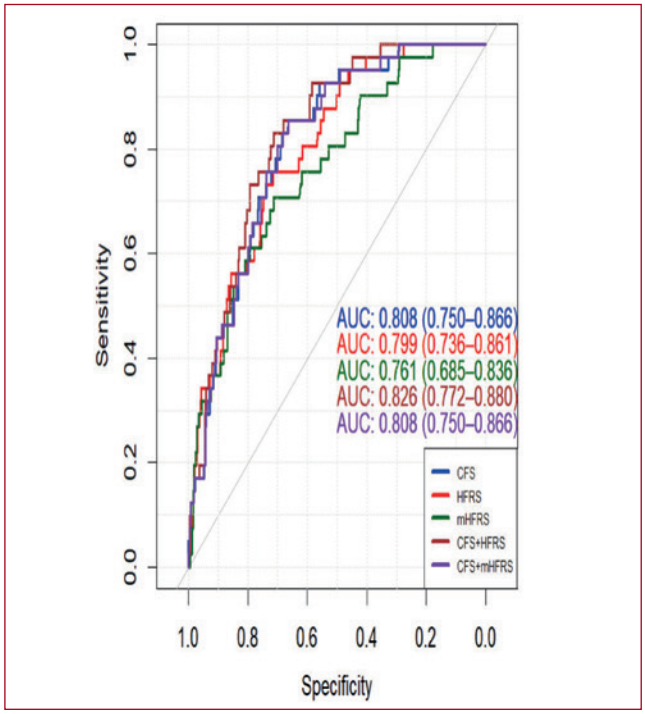

Figure 5. AUC ROC for 30d mortality had poorest performance for mHFRS alone (but still moderate); HFRS slightly poorer compared to CFS.

2. HFRS (standard methodology, index admission & 2 emergency admissions in 2 years).
3. mHFRS (2 emergency admissions in 2 years).

HFRS was a significant predictor of all outcomes, whereas mHFRS was a significant predictor of most outcomes with the following exceptions: high risk mHFRS

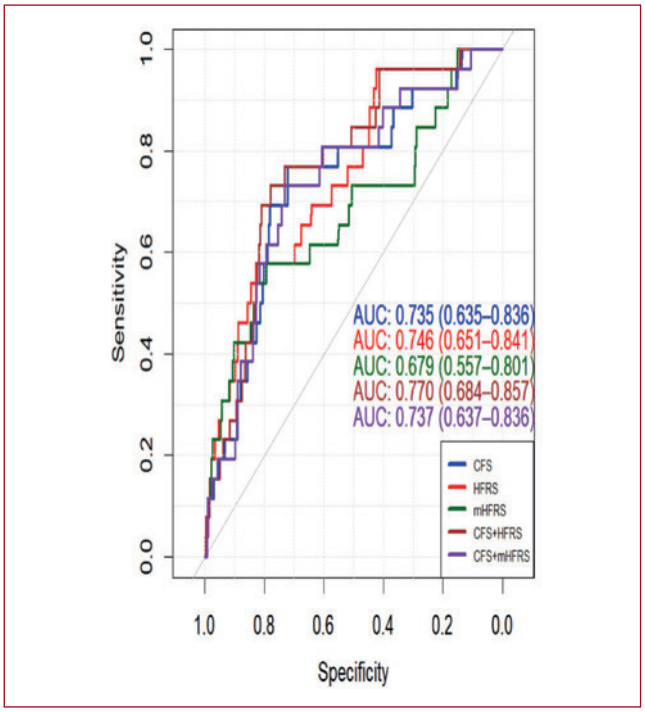

Figure 4. AUC ROC for inpatient mortality had poorest performance for mHFRS alone (but still moderate) and HFRS performed slightly poorer compared to CFS.

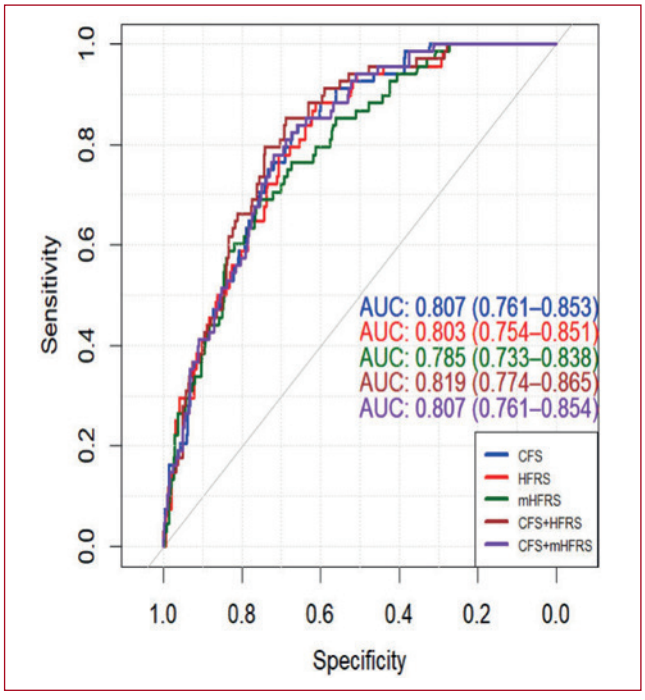

Figure 6. AUC ROC for 90d mortality had similar performance across all metrics.

Outcomes	AUC ROC* (95% CI)		
	CFS	HFRS	mHFRS
Length of Stay (LOS) LOS >=6 days	0.685 (0.642-0.729)	0.732 (0.691-0.774)	0.674 (0.631-0.718)
30-day Emergency Readmissions	0.666 (0.607-0.725)	0.673 (0.617-0.729)	0.684 (0.628-0.741)
Inpatient Mortality	0.735 (0.635-0.836)	0.746 (0.651-0.841)	0.679 (0.557-0.801)
30 day Mortality	0.808 (0.750-0.866)	0.799 (0.736-0.861)	0.761 (0.685-0.836)
90 day Mortality	0.807 (0.761-0.853)	0.803 (0.754-0.851)	0.785 (0.733-0.838)

**Models adjusted for patient's age, gender, body mass index and Charlson Comorbidity group. Abbreviations: CFS, Clinical Frailty Scale; HFRS, Hospital Frailty Risk Score; mHFRS, modified Hospital Frailty Risk Score; AUC ROC, Area under the Receiver Operating Characteristic curve.*

Table 7. Discriminative performance of the Frailty Risk Score to clinical outcomes.

for LOS, intermediate and high risk mHFRS for inpatient mortality and intermediate mHFRS for 30-day mortality. The higher AUC ROC values for HFRS compared to mHFRS indicate that HFRS has better predictive capability for LOS and mortality outcomes, while mHFRS has higher AUC ROC and thus better predictive capability for 30-day emergency readmissions.

Discussion

Our study has reviewed a large cohort (N=3042) of older patients (=>65 years) hospitalised after an attendance at the emergency department of an acute hospital in Singapore. Although not all older people are frail, the prevalence of frailty increases with age[4] and in this study frail patients identified using CFS were older (81.8 years, SD 8.41 vs 75.3 years SD 7.20, p<0.001) and more likely to be female (45.4% vs 55.9%, p<0.001). The high predictive risk of frailty for a range of adverse health outcomes[6,7] was reiterated in this study, where adverse outcomes for frail vs non-frail patients included prolonged LOS (=>6 days) (52.5% vs 31.5%, p<0.001), higher 30-day re-admissions (18.5% vs 9.9%, p<0.001), higher mortality during hospitalisation (6.1% vs 2.0%, p<0.001), as well as higher 30-day (9.1% vs 2.3%, p<0.001) and 90-day mortality (15.8% vs 5.1%, p<0.001) (Table 1).

The HFRS has been validated in many different populations[14-15,33-34] including a large nationwide cohort study of 785,127 patients conducted in the United States (US) in 2016, where it was strongly associated with short term mortality and readmissions among patients hospitalized for acute myocardial infarction, heart failure, or pneumonia, and the addition of HFRS to traditional comorbidity-based risk-prediction models significantly improved prediction of adverse outcomes in all three conditions[15]. Our prior work found risk of frailty varies in different cohorts of hospitalised patients, for example, 84% of older patients with community acquired pneumonia, were at risk of frailty, of whom, 50% of high risk patients had dementia and 77% had concomitant dysphagia[35], whereas only 49% of surgical patients were at risk of frailty[36]. Conversely. in a cross-sectional study, Chin et al. found that HFRS had poor sensitivity compared to CFS in the detection of frailty in patients with COPD. However, their study only included 99 patients and was limited to those who used the COPD clinical pathway during hospitalisation, which represents only a small subset of the frail, older hospitalised patients. Our study on the other hand includes a larger and wider cohort of patients.

As highlighted, the standard HFRS methodology[21] cannot be computed until the patient admission episode is coded, which typically occurs 6-8 weeks after hospital discharge and hence is not available during hospitalisation. To overcome this limitation, and to provide a scoring during hospitalisation, our study has used a modified version of HFRS which can be extracted directly from electronic health records to produce a frailty risk score during hospitalisation. Frailty measured by both CFS and HFRS was available for all 3042 patients, but mHFRS was only available for 1623 (53%) patients, as mHFRS cannot be computed for patients without any prior emergency admissions. However, scoring 53% of patients at hospital admission may reduce assessor burden and time taken to undertake frailty screening and this methodology could be introduced alongside established frailty tool such as the CFS.

Comparing the frailty scores, with CFS as the comparator, HFRS vs mHFRS identified 55.1% vs 34.4% of the severely frail, 40.8% vs 29.6% of the frail and 57.2% vs 81.7% of the non-frail patients (Table 1). Despite the decrease in clinical information available when the index admission is not

utilised, mHFRS was better at identifying non-frail patients and has better overall sensitivity (58.1%) and specificity (79.1%), although HFRS correctly identified severely frail patients. CFS does not correlate well with HFRS in all cohorts of hospitalised patients and a small study in patients with COPD showed HFRS vs CFS had a sensitivity of 27% and specificity of 93% to detect frail vs non-frail patients[37].

Our study has shown good overall ability of the CFS, HFRS and mHFRS to predict adverse outcomes in frail patients compared to non-frail patients and comparing the frailty scores, there was fair agreement (κ of 0.235) between the CFS and HFRS and a similar level of agreement between CFS and mHFRS (κ of 0.243) which suggests that HFRS and mHFRS are comparable. However, Spearman's correlation coefficient indicated a moderate positive monotonic relationship between CFS vs HFRS and CFS vs mHFRS, taken together with the fair agreement of Cohen's kappa and the statistically significant Mcnemer's test, this suggests that the modified version of the HFRS (mHFRS), as well as HFRS might capture different aspects of frailty compared to the CFS. In another large cohort of ED attenders, comparison of CFS and HFRS found only low or slight agreement between CFS and HFRS, although both scores were predictive of adverse outcomes, CFS was suggested to be more relevant to functional aspects of frailty, whereas HFRS focused more on multi and complex co-morbidity[38]. Although our study has utilised the CCI and CCI>=3 was shown to be a strong covariate of all outcomes (Table 5), there has been no other measure of function to compare with the frailty scores.

The understanding of frailty amongst Singapore's healthcare professionals is varied, within acute care settings there are many barriers to implementation of frailty screening which include lack of resources and staff perceptions regarding complexity in undertaking frailty assessments[39]. The methodology shown in this study overcomes these barriers as no clinical assessment is needed. A potential future application for mHFRS, would be to identify low risk patients attending the ED, utilising the score in the same way that community acquired pneumonia and be risk stratified using CURB-65. We have begun small scale testing of the mHFRS, with the aim of making frailty a "vital sign" that is highlighted during hospitalisation.

Study limitations include, firstly, that HFRS is based on routinely available data extracted from the electronic health record which was not primarily intended for research purposes but relies on accurate coding and inaccuracy of coding may create bias. There is potential bias in the methodology used for assigning mHFRS to patients with no prior admission, which may over-estimate the specificity of the tool. Secondly, using ICD-10 codes may miss other important components of frailty that may not be represented, such as polypharmacy and fatigue. Thirdly, this study included those admitted to an acute hospital following and ED attendance and did not include patients being discharged from the ED which could introduce selection bias. Additionally, HFRS does not take into consideration severity of comorbidities and patient's functional status which are important aspects of frailty assessment.

Overall, the comparisons indicate that mHFRS can be applied as a clinical tool and an adjunct to frailty screening which offers the opportunity to widen the understanding of frailty across other specialties where the multi-disciplinary team can be trained to deliver frailty interventions and potentially improve outcomes for older hospitalised patients.

Conclusion

In summary, mHFRS is a novel and comparable frailty risk stratification tool that provides a rapid, standardised, low cost and easily utilised tool for identification of frailty in older hospitalised patients and can be used alone or in combination with CFS.

Ethics Approval

National guidance under the Human Biomedical Research Act 2015, deems that the study does not fall into human research definition, as the study team only had access to fully anonymised routinely collected clinical data and hence review by SingHealth Centralised Review Board was not required. Data anonymization was undertaken by the the Data Management and Informatics team. All the methods included in this study are in accordance with the declaration of Helsinki.

Acknowledgements

The team would like to acknowledge and thank the UK Acute Frailty Network for their assistance and contribution to the frailty work and the Data Management and Informatics team at Changi General Hospital.

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Supplementary Information 1. List of 109 ICD codes and respective weights to compute HFRS.

ICD Code	ICD Description	Weight
F00	Dementia in Alzheimer's disease	7.1
G81	Hemiplegia	4.4
G30	Alzheimer's disease	4.0
I69	Sequelae of cerebrovascular disease (secondary codes)	3.7
R29	Other symptoms and signs involving the nervous and musculoskeletal systems (R29·6 Tendency to fall)	3.6
F05	Delirium, not induced by alcohol and other psychoactive substances	3.2
N39	Other disorders of urinary system (includes urinary tract infection and urinary incontinence)	3.2
S00	Superficial injury of head	3.2
W19	Unspecified fall	3.2
R31	Unspecified haematuria	3.0
B96	Other bacterial agents as the cause of diseases classified to other chapters (secondary code)	2.9
R41	Other symptoms and signs involving cognitive functions and awareness	2.7
I67	Other cerebrovascular diseases	2.6
R26	Abnormalities of gait and mobility	2.6
R56	Convulsions, not elsewhere classified	2.6
R40	Somnolence, stupor and coma	2.5
S06	Intracranial injury	2.4
T83	Complications of genitourinary prosthetic devices, implants and grafts	2.4
E86	Volume depletion	2.3
E87	Other disorders of fluid, electrolyte and acid-base balance	2.3
M25	Other joint disorders, not elsewhere classified	2.3
S42	Fracture of shoulder and upper arm	2.3
R54	Senility	2.2
F03	Unspecified dementia	2.1
W18	Other fall on same level	2.1
Z50	Care involving use of rehabilitation procedures	2.1
F01	Vascular dementia	2.0
L03	Cellulitis	2.0
S80	Superficial injury of lower leg	2.0
Z75	Problems related to medical facilities and other health care	2.0
E53	Deficiency of other B group vitamins	1.9
H54	Blindness and low vision	1.9
G20	Parkinson's disease	1.8
K59	Other functional intestinal disorders	1.8
N17	Acute renal failure	1.8
R55	Syncope and collapse	1.8
S22	Fracture of rib(s), sternum and thoracic spine	1.8

Supplementary Information 1. *(Cont. from previous page).*

ICD Code	ICD Description	Weight
Z60	Problems related to social environment	1.8
B95	Streptococcus and staphylococcus as the cause of diseases classified to other chapters	1.7
L89	Decubitus ulcer	1.7
Z22	Carrier of infectious disease	1.7
A41	Other septicaemia	1.6
I95	Hypotension	1.6
K26	Duodenal ulcer	1.6
L97	Ulcer of lower limb, not elsewhere classified	1.6
N19	Unspecified renal failure	1.6
R44	Other symptoms and signs involving general sensations and perceptions	1.6
G40	Epilepsy	1.5
J96	Respiratory failure, not elsewhere classified	1.5
M19	Other arthrosis	1.5
X59	Exposure to unspecified factor	1.5
Z87	Personal history of other diseases and conditions	1.5
E16	Other disorders of pancreatic internal secretion	1.4
M81	Osteoporosis without pathological fracture	1.4
N18	Chronic renal failure	1.4
R94	Abnormal results of function studies	1.4
S32	Fracture of lumbar spine and pelvis	1.4
S72	Fracture of femur	1.4
N28	Other disorders of kidney and ureter, not elsewhere classified	1.3
R33	Retention of urine	1.3
R69	Unknown and unspecified causes of morbidity	1.3
G31	Other degenerative diseases of nervous system, not elsewhere classified	1.2
G45	Transient cerebral ischaemic attacks and related syndromes	1.2
R32	Unspecified urinary incontinence	1.2
R45	Symptoms and signs involving emotional state	1.2
S09	Other and unspecified injuries of head	1.2
Y95	Nosocomial condition	1.2
A04	Other bacterial intestinal infections	1.1
A09	Diarrhoea and gastroenteritis of presumed infectious origin	1.1
J18	Pneumonia, organism unspecified	1.1
M79	Other soft tissue disorders, not elsewhere classified	1.1
S01	Open wound of head	1.1
W06	Fall involving bed	1.1
Z74	Problems related to care-provider dependency	1.1

Supplementary Information 1. *(Cont. from previous page).*

ICD Code	ICD Description	Weight
E55	Vitamin D deficiency	1.0
J69	Pneumonitis due to solids and liquids	1.0
R02	Gangrene, not elsewhere classified	1.0
R47	Speech disturbances, not elsewhere classified	1.0
Z93	Artificial opening status	1.0
E05	Thyrotoxicosis [hyperthyroidism]	0.9
H91	Other hearing loss	0.9
M41	Scoliosis	0.9
R63	Symptoms and signs concerning food and fluid intake	0.9
W01	Fall on same level from slipping, tripping and stumbling	0.9
W10	Fall on and from stairs and steps	0.9
I63	Cerebral Infarction	0.8
K92	Other diseases of digestive system	0.8
M80	Osteoporosis with pathological fracture	0.8
R13	Dysphagia	0.8
Z06	Agent resistant to penicillin and related antibiotics	0.8
Z99	Dependence on enabling machines and devices	0.8
F10	Mental and behavioural disorders due to use of alcohol	0.7
J22	Unspecified acute lower respiratory infection	0.7
N20	Calculus of kidney and ureter	0.7
R00	Abnormalities of heart beat	0.7
Y84	Other medical procedures as the cause of abnormal reaction of the patient	0.7
R79	Other abnormal findings of blood chemistry	0.6
Z73	Problems related to life-management difficulty	0.6
F32	Depressive episode	0.5
M48	Spinal stenosis (secondary code only)	0.5
S51	Open wound of forearm	0.5
Z91	Personal history of risk-factors, not elsewhere classified	0.5
D64	Other anaemias	0.4
E83	Disorders of mineral metabolism	0.4
L08	Other local infections of skin and subcutaneous tissue	0.4
M15	Polyarthrosis	0.4
K52	Other noninfective gastroenteritis and colitis	0.3
R11	Nausea and vomiting	0.3
R50	Fever of unknown origin	0.1