

Supplementary Online Content

Automated frailty screening at-scale for pre-operative risk stratification using the electronic frailty index

Kathryn E. Callahan, MD, MS, Clancy J. Clark, MD, Angela F. Edwards, MD, Timothy N. Harwood, MD, Jeff D. Williamson, MD, MHS, Adam W. Moses, MHA, PMP, James J. Willard, MAS, Joseph A. Cristiano, MD, Kellie Meadows, MSW, Justin Hurie, MD, Kevin P. High, MD, MS, J. Wayne Meredith, MD and Nicholas M. Pajewski, PhD

Supplementary FIGURE SF1. Electronic Frailty Index Components Derived from the Electronic Health Record

Supplementary FIGURE SF2. Construction of Patient Cohort

Supplementary TABLE ST1. Top ten most frequent surgical procedures by service line

Supplementary TABLE ST2. Demographic and clinical variables stratified by availability of the electronic Frailty Index (eFI) within the electronic health record

Supplementary TABLE ST3. Length of stay and discharge destination following surgery by ASA Class and frailty status based on the electronic Frailty Index (eFI)

Supplementary TABLE ST4. 30-day readmissions and all-cause mortality following surgery by ASA Class and frailty status based on the electronic Frailty Index (eFI)

Supplementary TABLE ST5. Discrimination for all-cause mortality, 30-day readmission, and need post-acute care services based on the electronic Frailty Index (eFI)

Supplementary FIGURE SF1. Electronic Frailty Index Components Derived from the Electronic Health Record

Chronic conditions (Diagnosis Codes)
1. Anemia
2. Rheumatoid arthritis or osteoarthritis
3. Atrial fibrillation
4. Stroke or transient ischemic attack
5. Renal disease
6. Diabetes
7. Dizziness or vertigo
8. Dyspnea
9. Falls
10. Fragility or fracture
11. Hearing impairment
12. Congestive heart failure
13. Valvular disease
14. Hypertension
15. Hypotension or syncope
16. Myocardial infarction
17. Coronary atherosclerosis & other heart disease
18. Melanoma
18. Blood-related cancer
18. Cancer (Excluding melanoma, skin cancers, or blood-related cancers)
19. Dementia
20. Osteoporosis
21. Parkinson's disease
22. Peptic ulcer
23. Peripheral vascular disease
24. Pulmonary disease
25. Skin ulcer
26. Thyroid disease
27. Urinary incontinence
28. Urinary system disease
29. Blindness or other vision defects
30. Weight loss
31. Depression
32. Mild liver disease
32. Moderate to severe liver disease
33. Chronic pain

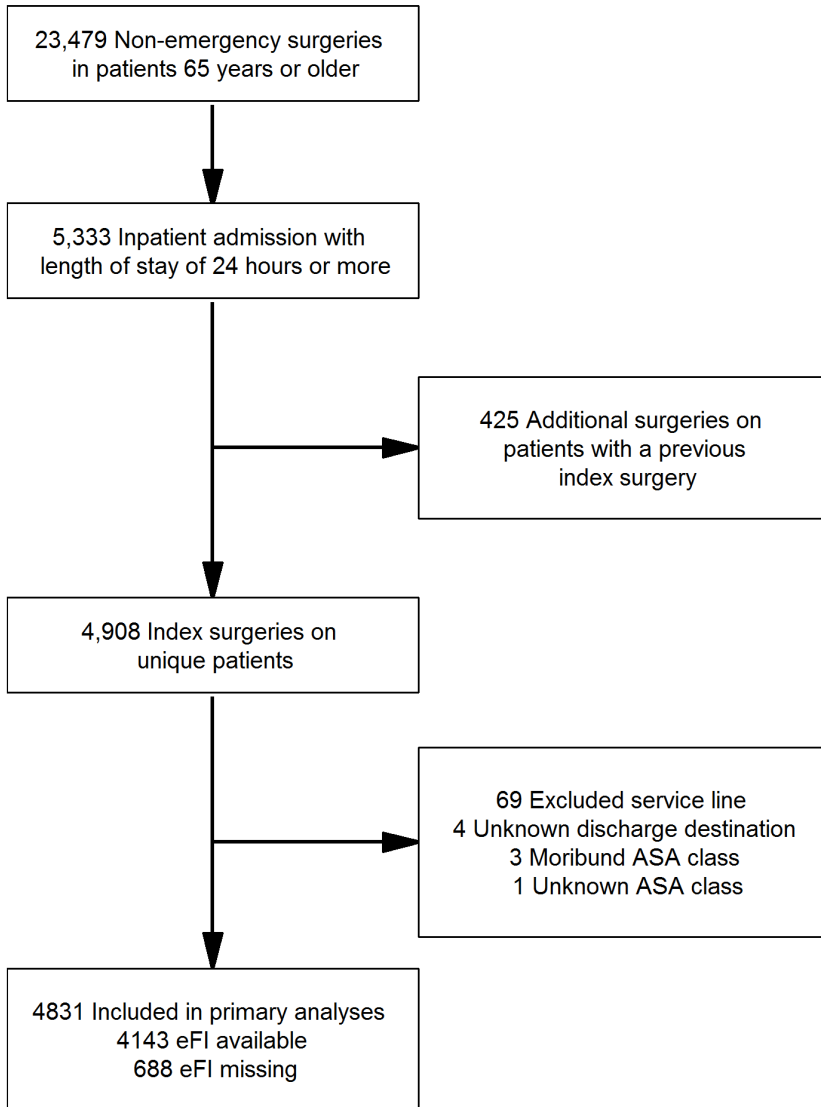
Vital Signs
34. Body mass index (Obesity)
35. Body mass index (Underweight)
14. Systolic & diastolic blood pressure

Laboratory measurements
5. Estimated glomerular filtration rate
36. Total cholesterol
37. HDL cholesterol
38. Triglycerides
39. Potassium
40. Sodium
32. Aspartate aminotransferase
41. Mean corpuscular volume
42. Blood urea nitrogen
43. Calcium
44. Albumin
45. Total protein
46. Alkaline phosphatase
47. Hemoglobin
6. Glucose

Function (Medicare Annual Wellness Visit)
48. Activities of daily living
49. Instrumental activities of daily living
50. Self-reported health status
51. Chair rise
19. Diagnosis of dementia or cognitive impairment
11. Hearing concerns / use of hearing aid
52. Stress
33. Pain

Other
53. Smoking status
54. Polypharmacy

Supplementary FIGURE SF2. Construction of Patient Cohort



ASA denotes American Society of Anesthesiologists and eFI electronic Frailty Index.

Excluded service lines (due to low volume of surgeries requiring an inpatient admission): Electroconvulsive Therapy (N= 7), Emergency General Surgery (N=7), Ophthalmology (N=16), Podiatry (N=9), Pulmonary (N=2), Transplant (N=9), and Trauma (N=19).

Supplementary TABLE ST1. Top ten most frequent surgical procedures by service line

Service Line	Procedure	No. (%)	Service Line	Procedure	No. (%)
Cardiothoracic (No. = 637)	CABG ON PUMP - CORONARY ARTERY BYPASS GRAFT	183 (28.7)	Orthopedics (No. = 1530)	TOTAL KNEE ARTHROPLASTY	626 (40.9)
	WEDGE RESECTION ROBOTIC	83 (13.0)		TOTAL HIP REPLACEMENT- ANTERIOR APPROACH	206 (13.5)
	AORTIC VALVE REPLACEMENT	76 (11.9)		TOTAL HIP REPLACEMENT - POSTERIOR APPROACH	174 (11.4)
	LUNG LOBECTOMY ROBOTIC	70 (11)		TOTAL KNEE REVISION	83 (5.4)
	CABG OFF PUMP	34 (5.3)		TOTAL SHOULDER REVERSE ARTHROPLASTY	59 (3.9)
	VATS / WEDGE RESECTION	27 (4.2)		TOTAL HIP REVISION	48 (3.1)
	MITRAL VALVE REPLACEMENT MVR	26 (4.1)		TOTAL SHOULDER ARTHROPLASTY	29 (1.9)
	MINIMALLY INVASIVE MITRAL VALVE REPAIR / REPLACEMENT	23 (3.6)		SHOULDER TOTAL UNCEMENTED	27 (1.8)
	MEDIASTINAL MASS RESECTION ROBOTIC	10 (1.6)		LUMBAR METREX DISCECTOMY	18 (1.2)
	VIDEO ASSISTED THORACIC SURGERY	10 (1.6)		POSTERIOR LUMBAR LAMINECTOMY	15 (1.0)
Ear, Nose, and Throat (No. = 327)	PAROTIDECTOMY	50 (15.3)	Plastics (No. = 65)	DEBRIDEMENT SACRAL WOUND	7 (10.8)
	LARYNGOSCOPY DIRECT	23 (7.0)		IRRIGATION & DEBRIDEMENT FOOT / ANKLE	4 (6.2)
	GLOSSECTOMY PARTIAL	20 (6.1)		IRRIGATION AND DEBRIDEMENT LOWER EXTREMITY	4 (6.2)
	SELECTIVE NECK DISSECTION	20 (6.1)		IRRIGATION & DEBRIDEMENT HAND	3 (4.6)
	MAXILLECTOMY	15 (4.6)		IRRIGATION & DEBRIDEMENT LEG	3 (4.6)
	MANDIBULECTOMY (PARTIAL) WITH PLATING	13 (4.0)		AMPUTATION BELOW KNEE	2 (3.1)
	THYROIDECTOMY	12 (3.7)		DEBRIDEMENT OPEN WOUND EACH ADDL 20 SQ CM (ADD-ON)	2 (3.1)
	LARYNGECTOMY TOTAL	10 (3.1)		IRRIGATION & DEBRIDEMENT UPPER EXTREMITY	2 (3.1)

	NECK DISSECTION MODIFIED RADICAL <6HRS	8 (2.4)		MOHS DEFECT REPAIR	2 (3.1)
	TRACHEOTOMY	8 (2.4)		ORIF MANDIBLE / MIDFACE	2 (3.1)
General Surgery (No. = 624)	RIGHT HEMICOLECTOMY LAPAROSCOPIC	33 (5.3)	Urology (No. = 390)	PROSTATECTOMY RADICAL W/ LYMPHADENECTOMY LAPAROSCOPIC ROBOT ASSISTED	110 (28.2)
	SIGMOID COLECTOMY LAPAROSCOPIC ASSISTED	32 (5.1)		NEPHRECTOMY PARTIAL ROBOTIC	45 (11.5)
	PARAESOPHAGEAL HERNIA REPAIR LAPAROSCOPIC	31 (5.0)		NEPHRECTOMY RADICAL ROBOTIC	33 (8.5)
	WHIPPLE PROCEDURE	31 (5.0)		CYSTECTOMY W/ ILEAL CONDUIT DIVERSION L1	17 (4.4)
	HYPERTHERMIC INTRAPERITONEAL CHEMOTHERAPY - MAJOR	27 (4.3)		PROSTATECTOMY SIMPLE - ROBOT ASSISTED	14 (3.6)
	LAPAROTOMY EXPLORATORY	22 (3.5)		NEPHRECTOMY PARTIAL W/ INTRAOP ULTRASOUND AND INTERPRETATION & INDOCYANINE GREEN FLUOROSCENCE IMAGIN	11 (2.8)
	DIAGNOSTIC LAPAROSCOPY	18 (2.9)		PROSTATECTOMY SIMPLE	10 (2.6)
	CHOLECYSTECTOMY LAPAROSCOPIC W/ CHOLANGIOGRAM	14 (2.2)		NEPHRECTOMY PARTIAL	9 (2.3)
	COMPONENT SEPARATION OPEN	14 (2.2)		PROSTATECTOMY LAPAROSCOPIC ROBOTIC	9 (2.3)
COLOSTOMY CLOSURE	12 (1.9)	NEPHRECTOMY RADICAL OPEN	8 (2.1)		
Gynecology (No. = 137)	HYSTERECTOMY TOTAL ABDOMINAL	38 (27.7)	Vascular (No. = 310)	CAROTID ENDARTERECTOMY	84 (27.1)
	LAPAROTOMY EXPLORATORY	25 (18.2)		PERCUTANEOUS AORTIC ENDOGRAFT	31 (10.0)
	HYSTERECTOMY TOTAL ROBOTIC	10 (7.3)		AORTIC ENDOGRAFT	25 (8.1)
	HYSTERECTOMY ABDOMINAL	7 (5.1)		FEMORAL ARTERY ENDARTERECTOMY	18 (5.8)
	SACRO-SPINAL LIG. SUSP./A&P REPAIR/URETHRAL SLING	5 (3.6)		ANEURYSM ABDOMINAL AORTA REPAIR (AAA)	16 (5.2)
	LAPAROTOMY EXPLORATORY / TUMOR DEBULKING / BOWEL RESECTION	4 (2.9)		AMPUTATION ABOVE KNEE	14 (4.5)

	EXAM UNDER ANESTHESIA (EUA)	3 (2.2)		FEMORAL DISTAL BYPASS	14 (4.5)
	HYSTERECTOMY ABD / BSO / OMENECTOMY / NODE DISSECTION	3 (2.2)		ARTERIOGRAM	13 (4.2)
	HYSTERECTOMY VAGINAL	3 (2.2)		FEMORAL ARTERY ARTERIOGRAM	11 (3.5)
	HYSTERECTOMY VAGINAL / BSO / A&P REPAIR	3 (2.2)		FEMORAL POPLITEAL BYPASS	8 (2.6)
Neurosurgery (No. = 811)	PLIF - POSTERIOR LUMBAR INTERBODY FUSION MULTI LEVEL	76 (9.4)			
	DEEP BRAIN STIMULATOR PHASE 1 ELECTRODE PLACEMENT	74 (9.1)			
	ANTERIOR CERVICAL DISCECTOMY & FUSION MULTI LEVEL	56 (6.9)			
	TRANSFORAMINAL LUMBAR INTERBODY FUSION	43 (5.3)			
	SPINAL FUSION POSTERIOR	39 (4.8)			
	VP SHUNT (VENTRICULO- PERITONEAL)	36 (4.4)			
	MAST MIDLINE PLIF	34 (4.2)			
	LUMBAR LAMINECTOMY MULTI LEVEL	32 (3.9)			
	ANTERIOR CERVICAL DISCECTOMY & FUSION /W PLATES	25 (3.1)			
	CRANIOTOMY FOR TUMOR	25 (3.1)			

Supplementary TABLE ST2. Demographic and clinical variables stratified by availability of the electronic Frailty Index (eFI) within the electronic health record

Characteristic	eFI			P value
	Overall	Available	Insufficient Data for eFI	
	N = 4831	N = 4143	N = 688	
Age, years, Mean (SD)	73.2 (5.9)	73.1 (5.8)	73.5 (6.4)	0.13
Male sex, No. (%)	2550 (52.8)	2145 (51.8)	405 (58.9)	0.001
Race / Ethnicity, No. (%)				0.18
White	4226 (87.5)	3619 (87.4)	607 (88.2)	
Black or African-American	461 (9.5)	407 (9.8)	54 (7.8)	
Hispanic	55 (1.1)	45 (1.1)	10 (1.5)	
Other	89 (1.8)	72 (1.7)	17 (2.5)	
Weighted Charlson Comorbidity Index, median [IQR]	1 [0 to 3]	1 [0 to 3]	0 [0 to 2]	<0.001
ASA Class, No. (%)				<0.001
No disease (I) or mild systemic disease (II)	824 (17.1)	687 (16.6)	137 (19.9)	
Severe systemic disease(III)	3175 (65.7)	2806 (67.7)	369 (53.6)	
Life-threatening systemic disease (IV)	832 (17.2)	650 (15.7)	182 (26.5)	
Operating room service line, No. (%)				<0.001
Orthopedics	1530 (31.7)	1373 (33.1)	157 (22.8)	
Neurosurgery	811 (16.8)	714 (17.2)	97 (14.1)	
Cardiothoracic	637 (13.2)	500 (12.1)	137 (19.9)	
General surgery	624 (12.9)	565 (13.6)	59 (8.6)	
Urology	390 (8.1)	317 (7.7)	73 (10.6)	
Ear, Nose, and Throat	327 (6.8)	240 (5.8)	87 (12.6)	
Vascular	310 (6.4)	269 (6.5)	41 (6.0)	
Gynecology	137 (2.8)	120 (2.9)	17 (2.5)	
Plastics	65 (1.3)	45 (1.1)	20 (2.9)	
Length of stay, hours, median [IQR]	76 [36 to 150]	75 [34 to 142.5]	101.5 [51 to 208]	<0.001
Frailty status, No. (%)				<0.001
Fit (eFI≤0.10)		1410 (34.0)		
Pre-Frail (0.10<eFI≤0.21)		2109 (50.9)		
Frail (eFI>0.21)		624 (15.1)		

SD denotes Standard Deviation, IQR Interquartile Range, and ASA denotes American Society of Anesthesiologists.

Supplementary TABLE ST3. Length of stay and discharge destination following surgery by ASA class and frailty status based on the electronic Frailty Index (eFI)

ASA Class	Frailty Status ^a	No.	Length of Stay (Hours) Median [IQR]	Discharge Destination				Odds Ratio (95% CI) ^c
				Died in Hospital	Transitional Care Facility ^b	Home With Home Health	Home	
No disease or mild systemic disease (I/II)	Fit	380	35 (29 – 71)	0 (0.0)	25 (6.6)	40 (10.5)	315 (82.9)	-
	Pre-Frail	283	42 (29 - 73)	1 (0.4)	20 (7.1)	25 (8.8)	237 (83.7)	0.84 (0.55 – 1.30)
	Frail	24	33 (29 – 55.5)	0 (0.0)	2 (8.3)	1 (4.2)	21 (87.5)	0.60 (0.17 – 2.15)
	eFI missing	137	48 (30 – 79)	0 (0.0)	19 (13.9)	15 (10.9)	103 (75.2)	1.64 (1.00 – 2.68)
Severe systemic disease (III)	Fit	881	74 (47 – 129)	9 (1.0)	101 (11.5)	148 (16.8)	623 (70.7)	-
	Pre-Frail	1497	74 (36 – 127)	7 (0.5)	228 (15.2)	261 (17.4)	1001 (66.9)	1.09 (0.90 – 1.32)
	Frail	428	79 (49 – 129)	4 (0.9)	105 (24.5)	88 (20.6)	231 (54.0)	1.75 (1.36 – 2.26)
	eFI missing	369	81 (51 – 189)	2 (0.5)	75 (20.3)	61 (16.5)	231 (62.6)	1.35 (1.03 – 1.78)
Life-threatening systemic disease (IV)	Fit	149	156 (106 – 249)	1 (0.7)	38 (25.5)	20 (13.4)	90 (60.4)	-
	Pre-Frail	329	147 (81 – 221)	5 (1.5)	72 (21.9)	73 (22.2)	179 (54.4)	1.34 (0.89 – 2.02)
	Frail	172	152 (81 – 250)	10 (5.8)	60 (43.9)	28 (16.3)	74 (43.0)	1.93 (1.21 – 3.08)
	eFI missing	182	196 (131 – 347)	7 (3.8)	63 (34.6)	35 (19.2)	77 (42.3)	2.10 (1.33 – 3.30)

ASA denotes American Society of Anesthesiologists, CI Confidence Interval, and IQR Interquartile Range.

^aFrailty status defined as Fit (eFI≤0.10), Pre-Frail (0.10<eFI≤0.21), or Frail (eFI>0.21).

^bTransitional Care Facility includes inpatient rehabilitation, skilled nursing facility, hospice, other long-term acute care or intermediate care facility, or transfer to another hospital.

^cDenotes adjusted odds ratio for the probability of dying in hospital, being discharged to transitional care facility, or being discharged home with home health (versus being discharged home without home health) based on a mixed-effects logistic regression model with a service line random effect, adjusting for age, sex, and race/ethnicity. For ASA class of no disease or mild systemic disease, due to model instability, estimates based on logistic regression without service line random effect.

Supplementary TABLE ST4. 30-day readmissions and all-cause mortality following surgery by ASA Class and frailty status based on the electronic Frailty Index (eFI)

ASA Class	Frailty Status ^a	30-day Readmission			All-Cause Mortality			
		No. ^b	No. (%)	Odds Ratio (95% CI) ^c	No.	30-day No. (Cum Inc)	180-day No. (Cum Inc)	Hazard Ratio (95% CI) ^d
No disease or mild systemic disease (I/II)	Fit	380	10 (2.6)	-	380	0 (0.0)	1 (0.3)	-
	Pre-Frail	282	13 (4.6)	1.82 (0.78 – 4.21)	283	1 (0.4)	3 (1.1)	4.14 (0.43 – 39.79)
	Frail	24	0 (0.0)	Not Estimable	24	0 (0.0)	0 (0.0)	Not Estimable
	eFI missing	137	6 (4.4)	1.67 (0.59 – 4.70)	137	1 (0.7)	2 (1.5)	4.72 (0.43 – 52.23)
Severe systemic disease (III)	Fit	872	50 (5.7)	-	881	12 (1.4)	27 (3.1)	-
	Pre-Frail	1490	99 (6.6)	1.25 (0.88 – 1.78)	1497	15 (1.0)	56 (3.8)	1.32 (0.83 – 2.09)
	Frail	424	44 (10.4)	2.21 (1.44 – 3.39)	428	8 (1.9)	25 (6.0)	2.29 (1.32 – 3.97)
	eFI missing	367	23 (6.3)	1.13 (0.68 – 1.89)	369	3 (0.8)	25 (7.0)	2.05 (1.18 – 3.56)
Life-threatening systemic disease (IV)	Fit	148	10 (6.8)	-	149	2 (1.4)	7 (4.8)	-
	Pre-Frail	324	38 (11.7)	1.87 (0.91 – 3.87)	329	7 (2.2)	27 (8.6)	1.80 (0.78 – 4.15)
	Frail	162	31 (19.1)	3.46 (1.63 – 7.36)	172	9 (5.4)	31 (19.9)	3.94 (1.72 – 9.03)
	eFI missing	175	12 (6.9)	1.04 (0.44 – 2.48)	182	8 (4.5)	20 (11.6)	2.42 (1.02 – 5.74)

ASA denotes American Society of Anesthesiologists, CI Confidence Interval, and Cum Inc Cumulative Incidence.

^aFrailty status defined as Fit (eFI≤0.10), Pre-Frail (0.10<eFI≤0.21), or Frail (eFI>0.21).

^bPatients discharged alive from hospital admission for index surgery.

^cDenotes adjusted odds ratio for the probability of being readmitted within 30 days based on a mixed-effects logistic regression model with a service line random effect, adjusting for age, sex, and race/ethnicity. For ASA class of no disease or mild systemic disease, due to model instability, estimates based on logistic regression without service line random effect.

^dDenotes adjusted hazard ratio for all-cause mortality based on a Cox proportional hazards regression model with the baseline hazard function stratified by service line, adjusting for age, sex, and race/ethnicity.

Supplementary TABLE ST5. Discrimination for all-cause mortality, 30-day readmission, and need post-acute care services based on the electronic Frailty Index (eFI)

Outcome	Model	C-statistic
All-cause mortality	eFI only	0.62
All-cause mortality	eFI plus	0.75
30-day readmission	eFI only	0.60
30-day readmission	eFI plus	0.66
Need for Post-Acute Care Services	eFI only	0.59
Need for Post-Acute Care Services	eFI plus	0.71

Post-acute care services includes being discharged to transitional care facility or being discharged home with a need home health services. eFI plus model includes age, sex, race/ethnicity, American Society of Anesthesiologists class, and service line as covariates, in addition to the eFI. C-statistics based on 10-fold cross-validation