Clinical Utility of the Risk Analysis Index as a Prospective Frailty Screening Tool within a Multi-Practice, Multi-Hospital Integrated Healthcare System

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ABSTRACT

Background: Prior studies demonstrate the validity of the Risk Analysis Index (RAI) for evaluating preoperative frailty, but they have not demonstrated the feasibility of its implementation within routine clinical practice. The goal of this project was to first address barriers to implementation of the RAI within a large, multi-hospital, integrated healthcare delivery system, and to subsequently demonstrate its utility for identifying at-risk surgical patients.

Methods: Implementation of the RAI as a frailty screening instrument began as a quality improvement initiative at the University of Pittsburgh Medical Center in July 2016. RAI scores were collected within a REDCap survey instrument integrated into the outpatient electronic health record and then linked to information from additional clinical datasets. NSQIP-eligible procedures were queried within 90 days following the RAI, and the association between RAI and postoperative mortality was evaluated using logistic regression and Cox proportional hazards models. Secondary outcomes such as inpatient length of stay and readmissions were also assessed.

Results: RAI assessments were completed on 36,261 unique patients presenting to surgical clinics across five hospitals from July 1 to December 31, 2016, and 8,172 of these underwent NSQIP-eligible surgical procedures. The mean RAI score was 23.6 (SD 11.2), the overall 30-day and 180-day mortality after surgery was 0.7% and 2.6%, respectively, and the median time required to collect the RAI was 33 [IQR 23-53] seconds. Overall clinic compliance with the recommendation for RAI assessment increased from 58% in the first month of the study period to 84% in the sixth and final month. RAI score was significantly associated with risk of death (HR=1.099 [95% C.I.: 1.091 – 1.106], $p<0.001$). At an RAI cutoff of ≥37, the positive predictive values for 30- and 90-day readmission were 14.8% and 26.2%, respectively, and negative predictive values were 91.6% and 86.4%, respectively.

Conclusions: The RAI frailty screening tool can be efficiently implemented within multi-specialty, multi-hospital healthcare systems. In the context of our findings and given the value of the RAI in predicting adverse postoperative outcomes, health systems should consider implementing frailty screening within surgical clinics.

Introduction

The United States (US) population is aging rapidly, and by 2040, the number of persons in the US over age 65 will double while those over age 85 will more than double[1]. Because patients over 65 years of age undergo almost one-third of surgical procedures in the US, this growing segment of the population represent an important group for surgeons, hospitals, and health systems[2,3]. Though previous observational studies have identified frail patients as being at risk for adverse consequences following surgery[4–6], recent work has emphasized that even when these patients undergo "low risk" procedures they experience mortality at a rate significantly higher than their robust counterparts[7]. Therefore, preoperative frailty screening provides a novel mechanism to not only identify these at-risk patients, but more importantly provides a mechanism for targeting enhanced perioperative resources to those who may benefit most. Several frailty instruments have been studied retrospectively in surgical populations, but evidence for their use in a system-wide screening program is lacking. Our previous work has attempted to fill this knowledge gap by describing initial development and validation of the Risk Analysis Index (RAI), a prospective frailty assessment tool suitable for use at the point of care to guide preoperative decision making[8,9].

The RAI is rooted in the "deficit accumulation" model of frailty, and unlike the "phenotype" model of frailty, it does not require physical performance measures like grip strength or gait speed[10]. The RAI is scored on a weighted scale based on responses to 14 survey items including age, sex, weight loss, loss of appetite, chronic kidney disease, congestive heart failure, shortness of breath, living arrangements (independent vs. assisted), activities of daily living (ADLs), and presence of malignancy. It was developed within the Surgical Service Line at the Veterans Affairs (VA) Nebraska-Western Iowa Health Care System (NWIHCS), and its initial development focused on the clinical form of the RAI (RAI-C) completed through direct patient interview[8]. The NWIHCS Surgical Service Line used the RAI-C at the point of care to screen all patients scheduled for elective surgery and preoperatively deploy a complex

behavioral intervention for frail patients—this intervention was associated with a nearly three-fold reduction in the odds of mortality among frail patients and increased engagement of palliative care services[11,12]. Subsequent work has tailored the scoring paradigm specifically to surgical populations, providing robust data for its introduction into routine clinical practice[9].

Despite favorable early experiences with the RAI-C, concerns remain regarding it's the clinical utility within a large, multi-hospital, integrated healthcare delivery system. This project had two main goals. The first, was to address barriers to implementation of the RAI as a prospective frailty screening tool within a broad range of surgical subspecialties and practice settings. Second, after identifying a mechanism to facilitate implementation, we conducted a prospective, observational cohort study to identify the RAI-C's association with clinically-meaningful outcomes in a non-Veteran population typical of private-sector surgery in the United States.

Methods

Study Context

The University of Pittsburgh Medical Center (UPMC) is a growing, multi-hospital healthcare system. In addition to serving physicians in private practice, it manages a multi-specialty physician group, University of Pittsburgh Physicians (UPP), focused primarily at five hospitals in the greater Pittsburgh, PA region. In order to drive change aimed at reducing low-value, high-cost surgical care, senior leadership at UPMC decided to implement the RAI-C (hereafter RAI) across its system as part of a quality improvement initiative reviewed and approved by the UPMC Quality Review Committee (Protocol #986).

Successful implementation necessitated a project which accomplished two primary goals: (1) to refine the RAI such that it becomes an instrument agile enough to fit within the clinical workflow of this diverse, high-volume clinical environment and (2) to confirm the RAI's ability to predict post-surgical

outcomes when prospectively implemented in this environment. Implementation was guided by staff from the Wolff Center at UPMC, an interdisciplinary quality improvement center. After revising the survey instrument for ease of use through an iterative process of pilot tests among survey methodologists and patients, UPP surgical practices were instructed to complete the RAI on all new patients presenting to outpatient surgical clinics beginning July 1, 2016.

Implementation of Prospective Frailty Screening Using the RAI

Detailed descriptions of the development and initial validation of RAI have been published previously[8,9]. In preparation for pilot testing and implementation, an online RAI calculator (eFigure 1) was created to capture survey response data and provide real-time scoring using REDCap [13]. This instrument and all associated data were stored on the HIPAA-compliant servers of UPMC and use of the tool was approved for clinical use by the Information Technology security group at UPMC. Implementation of the RAI as a screening instrument began as a quality improvement initiative with a pilot phase from January to June 2016 in eight surgical clinics. During this period, an implementation specialist (MKW) was assigned to educate staff from the surgical practices regarding completion of the RAI. She was subsequently responsible for interfacing with practice managers, nurses, medical assistants and physicians in a process of iterative refinement and optimization to adapt RAI assessment to the needs of their clinical workflow.

During the initial pilot period the RAI was administered by clinical staff by directly asking the patients each question with real-time entry into the REDCap instrument, but initial feedback using this method revealed concerns regarding efficiency of clinic operation. To reduce the time required of clinical staff, survey methodologists at the Wolff Center of UPMC revised the RAI into format suitable for direct completion by patients, which included rephrasing the questions and ensuring reading comprehension at an 8th-grade level. Initial testing of this patient-facing questionnaire revealed issues

with the renal dysfunction and cancer-related elements, both of which require medical insight to answer. The kidney dysfunction item was rephrased to capture any renal disease excluding kidney stones. The cancer element was rephrased to capture all patients presenting with any malignancy within five years of the visit. The final patient-facing questionnaire (eFigure 2) was then mailed to all new clinic patients or provided to them when they arrived for their clinic visit and completed by the patient or their surrogate. Age and sex were not included in this form as they were entered directly via data pass-through from the electronic health record. Medical assistants verified the responses, adjusting responses if clinically indicated (e.g., dementia) and entered responses into the REDCap instrument which immediately returned the corresponding RAI score.

To prepare for system-wide implementation, the REDCap instrument was next integrated into the outpatient the electronic health record (EHR) system (EPIC Systems, Verona, WI). This integration allowed for RAI score to be captured within a result flowsheet and a Best Practice Alert to be displayed to the provider showing the calculated score. The bidirectional linkage also captured patient identifiers within the REDCap database providing a mechanism for linkage to other clinical data sources within the health system. After the initial pilot period, frailty screening was implemented in all clinics within the target surgical specialties (thoracic surgery, orthopedic surgery, plastic surgery, general surgery, cardiac surgery, neurosurgery, otolaryngology, urology, obstetrics/gynecology). Providers within these clinics were asked to meet a benchmark of 80% compliance in using the instrument to assess all new and preoperative patients presenting to outpatient surgical clinics and a portion of their salary compensation was contingent on meeting this benchmark. Compliance was monitored by measuring acknowledgement of the Best Practice Alert for all eligible visit types. Since RAI instruments were completed directly by the patients or their surrogates, the definition of time required for completion was defined as the time spent by clinical staff in collecting and entering the data in the electronic survey instrument.

Predictive Accuracy of the RAI

RAIs from July 1 to December 31, 2016 were captured. We constructed an analytic dataset by linking RAI responses from the REDCap database to other parts of the EHR. We then queried the EHR for Common Procedural Terminology (CPT) codes performed within 90 days of each RAI assessment, retaining only those eligible for abstraction and inclusion within the American College of Surgeons National Surgical Quality Improvement Program® (ACS NSQIP®)[14]. If a patient took multiple RAI assessments within this timeframe, we retained one assessment selected at random. We also linked each RAI record to a vital statistics file to obtain dates of death from which we calculated survival length from the date of a surgical procedure. For those patients admitted to the hospital as an inpatient for their index procedure, we captured length of stay and whether they experienced 30-day and/or 90-day inpatient readmission. We also assessed whether and for how long they were admitted to an intensive care unit (ICU) during their stay.

The Kaplan-Meier estimator was used to plot survival curves stratified by RAI score, and the association between RAI and survival was assessed using a Cox proportional hazard model[15]. We specifically omitted multivariable modeling techniques because the RAI is a composite of risk-factors, and inclusion of standard risk-related covariables result in significant collinearity. Though previous work has detailed the validity of the RAI when applied retrospectively, we used similar methods to confirm these findings when the RAI is used prospectively. Logistic regression models were constructed to evaluate the association between RAI and 180-day mortality. Model discrimination and goodness-of-fit was assessed with c-statistics, the Akaike Information Criteria (AIC) and Maximum R^2[16,17]. We also calculated sensitivity, specificity, positive predictive value, negative predictive value and prevalence for each RAI value. To assess calibration, we calculated the absolute value of the difference between the observed and predicted mortality for each RAI value, reporting the median difference and the interquartile range. Across all RAI values, we reported the proportion of cases where the exact 95%

confidence interval (95% C.I.) for the observed mortality included the predicted mortality, calling this statistic "overlap" as described elsewhere[9,18]. To visually display changes in calibration we plotted the predicted mortality across the range of RAI scores along with the mean RAI score observed for each RAI value with exact confidence intervals. Differences in c-statistics between genders were assessed using nonparametric methods as described in [19]. Finally, sensitivity, specificity, positive predictive value, and negative predictive value were calculated for readmission, LOS, and ICU LOS at the RAI threshold of 37. The threshold of 37 was chosen based prior published work demonstrating that this corresponds to the highest risk decile of patients, who suffer at least twice the average mortality observed in a contemporary cohort[9].

The threshold for statistical significance was set to $p < 0.05$, and all statistical analyses were performed using Stata/SE 15.1 (StataCorp LLC, College Station, TX).

Results

Implementation of the RAI

From July 1 to December 31, 2016, 42,738 RAI assessments were prospectively completed. These assessments were linked to 36,261 unique patients presenting to surgical clinics across five hospitals. Of these, 8,172 patients were subsequently matched to a NSQIP-eligible CPT code. The cohort contained 931 unique CPT codes, the most common of which were laparoscopic cholecystectomy, segmental mastectomy, inguinal herniorrhaphy, arthroscopic rotator cuff repair, and both knee and hip arthroplasty (eTable 1 lists the 167 procedures with at least 10 occurrences by decreasing frequency). No individual CPT accounted for more than 3.8% of the cohort.

Demographic characteristics of the sample are described in Table 1 and are reflective of the UPMC patient population. 43.7% were male, the mean age was 57.5 (SD 16.0) years, the mean RAI score was 23.6 (SD 11.2), the overall 30-day and 180-day mortality rates after surgery were 0.7% and 2.6%,

respectively, and the mean/median time required to collect the RAI was 47.5 (SD 51.4) seconds and 33 [IQR 23-53] seconds, respectively. Across the range of subspecialties incentivized for completion of the RAI, 15-95% of eligible patient encounters had an RAI score documented within the EMR (Figure 1). Overall compliance with the recommendation for RAI assessment increased from 56% in the first month of the study period to 86% in the sixth and final month.

Validation of the RAI within the Institutional Cohort

When implemented prospectively, model discrimination for 180-day mortality was comparable to performance in our prior retrospective analyses (C = 0.815, 95% C.I.: 0.788 – 0.842). Calibration was also very good in that the observed and predicted mortality rates rarely differed by more than more than 1-2%, and the 95% C.I. for observed mortality overlapped predicted mortality for 95.6% of individual RAI values (Figure 2, eTable 2). Since the original RAI was developed in a Veteran population which is >97% male, we performed an additional subgroup analysis to confirm that predictive ability of the RAI was similarly independent of patient sex. Differences in discrimination were tested between men and women at both 30- and 180-days with p = 0.914 and p = 0.224, respectively (eTable 2). Finally, Table 2 presents the sensitivity, specificity, PPV, and NPV for 180-day mortality, and prevalence of frailty at the threshold values of 30, 37, 45 and 53. These values are available for each discrete RAI value in eTable 3.

RAI Association with Clinical Outcomes

Prior work with the RAI was limited to analyzing patient survival using binary variables due to limitations related to existing surgical quality improvement clinical registries (i.e.: data from the Veterans Affairs Surgical Quality Improvement Program and ACS-NSQIP). As our data allowed calculation of specific survival time for each subject, we were able to use Cox regression and Kaplan-Meier curves to document the association between RAI and risk of death. The hazard for risk of death was 9.9% greater

for each 1-point increase in RAI (HR = 1.099, 95% C.I.: 1.091 – 1.106, p < 0.001) (Figures 3,4). Of the 8,172 surgical encounters, 3,500 (42.8%) were linked to corresponding inpatient visits within 90 days. Within this inpatient cohort 510 (14.6%) experienced a LOS >7 days and 146 (4.2%) experienced a LOS >14 days. Likewise, 748 (21.4%) experienced any ICU stay during their hospital visit, 116 (3.3%) an ICU LOS >4 days, and 68 (1.9%) an ICU LOS >7 days. After excluding 39 patients who experienced inpatient mortality, 341 (9.9%) experienced 30-day readmission and 565 (16.3%) experienced 90-day readmission. When evaluated using logistic regression models, RAI demonstrated a dose-dependent association with each of these outcomes (Figure 4, eTable 4).

To provide context to the association between RAI and 180-day mortality, we also assessed the association between ASA class and 180-day mortality in the same cohort. In the subset of patients with both a documented ASA and RAI score (n=7378, 82.5%), the AUC for RAI and ASA were not significantly different (C=0.823 vs. C=0.820, respectively; p = 0.478) (eFigure 3). However, we also noted an increase in AUC when using both scores in predictive models, indicating a synergistic effect when including both RAI and ASA (C=0.890 vs. C=0.823, P < 0.001).

Finally, we evaluated the performance of the RAI as a diagnostic test for frailty by calculating the sensitivity, specificity, PPV, and NPV at an RAI threshold of 37 (as described in methods) for each of the clinical outcomes (Table 3). This demonstrated the potential clinical utility of the RAI, as it reliably identified patients associated with increased utilization of healthcare resources.

Discussion

With an ever-increasing focus on the quality and safety of surgical care and shared decision-making, clinicians need informative preoperative tools that can help to identify frail patients at risk for adverse postoperative outcomes. Despite an abundance of tools that could be used for this purpose, many are not ideally designed to support enterprise-level scalability. For example, tools assessing the

frailty "phenotype"[4] are less practical for routine screening in large health systems because they require time and effort from clinical staff to measure walking speed and grip strength. Other preoperative risk assessment tools could also be considered for this purpose, even if they were not specifically developed as frailty instruments. The ACS-NSQIP calculator is an online tool that allows the provider to enter numerous data points and returns an estimate of a given patient's perioperative risk for a variety of adverse outcomes[14]. Despite robust evidence to support its predictive performance for these outcomes in cross-sectional analyses of NSQIP data, inherent in its design are limitations which limited feasibility of implementation within our practice setting. Chiefly these limitations included the time required to manually enter the numerous data points and the proprietary, closed-source nature of the calculator which prevents direct EMR integration. By comparison the RAI is a parsimonious and open source tool which compares favorably to other frailty screening tools[8], has excellent validity across a variety of patient populations[9], and is strongly associated postoperative outcomes. Most importantly the RAI can be completed by a provider or the patient themselves in less than 1 minute and integrated directly into an existing EMR, underpinning its utility as a practical choice for prospective frailty screening in the clinical workflow of large health systems.

This study does not represent the first implementation of a preoperative frailty screening instrument[20–23], but it is unique in both its use of a mature screening instrument—the RAI—and also in its size and scope. By developing the RAI as a patient-facing questionnaire, providing EHR integration, and incentivizing providers for its completion, 77% of eligible patients were screened within the first 6 months of implementation. To our knowledge this study represents the largest reported cohort of patients with a prospectively measured frailty assessment performed within the context of surgical clinical workflow. More importantly, these scores were measured within a diverse set of discrete surgical clinics and not performed within a dedicated preoperative assessment clinic, thus allowing the RAI to inform the decision to operate. Though clinicians were always able to adjust patient responses

based on their exam, in practice the overwhelming majority of these values rely exclusively on patient report. These points are critical to demonstrating the RAI's value as a broad screening instrument since it required neither the dedicated expertise of specific providers or additional clinic time beyond the index surgical visit.

Though the initial goal of this study was to evaluate the use of the RAI at scale across a multi-hospital health system, the long-term utility of this effort hinges upon the RAI's ability to provide clinically meaningful information to patients and providers at the point of care. We therefore first confirmed that when implemented prospectively the RAI maintains excellent discrimination and calibration in predicting 180-day mortality. More importantly, we identified dose-dependent relationships between the RAI and clinically-relevant outcomes including mortality, LOS, ICU LOS and readmission. Patients scoring ≥37 on the RAI had approximately 60% higher rates of 30-day and90-day readmissions (≥37 on RAI 15.3% vs. <37 on RAI 9.9% and 27.0% vs. 16.3%, respectively), almost twice the rate of an extended LOS >14 days (8.1% vs. 4.2%), and almost twice the rates of ICU stays lasting >4 and >7 days (6.2% vs. 3.3% and 3.6% vs. 1.9% respectively). This further confirms that frail patients require more healthcare resources and suffer worse outcomes as compared to their more robust counterparts. This is consistent with previous studies documenting the financial implications of treating frail patients[24,25].

When compared to other standard risk-assessment measures such as the ASA, the RAI performs favorably. In predicting 180-day mortality, the AUC for the RAI and ASA were not statistically different. Though it might be expected that use of both instruments results in minimal improvement due to significant collinearity, we instead discovered that the combination of RAI and ASA demonstrated an AUC significantly greater than either alone. This can be interpreted to mean that each score measures unique facets of risk: the ASA evaluating comorbidity while the RAI incorporates elements of frailty. In addition, although ASA is often scored by the anesthesiologist at the time of surgery, it has never been

proven feasible for deployment upstream, thus limiting its utility for decision making regarding surgical intervention. This study demonstrates the feasibility of the RAI to provide reliable risk stratification just in time at the point of care.

Experience from the current study provides insight into the feasibility and validity of the RAI as a generalizable instrument for preoperative frailty assessment. However, we emphasize that there is no gold standard for measuring frailty, and although the RAI is highly specific, its sensitivity is only modest. In other words, in clinical practice the RAI should be used as the first step (i.e.: identifying potentially frail patients at risk for suboptimal outcomes) in a two-stage screening paradigm, as has been described in similar investigations related to frailty and end-of-life care[26,27]. Using this strategy, patients scoring below 37 can reliably expect outcomes at or below those typical for the average patient (NPV = 98.6% for 180-day mortality), and for these patients no further testing is warranted. By contrast, those scoring at or above 37 should be considered potentially frail (PPV = 10.7% for 180-day mortality) and deserve further testing with more intensive frailty measures to confirm the diagnosis.

It is important to note that evaluating the impact of frailty assessment on clinical decision making was outside the scope of this study. Routine frailty measurement may have influenced provider decision making, but this would only be expected to impact the number of frail patients undergoing surgery as opposed to biasing the observed association between RAI and mortality for those who did proceed to surgery. Given the success of implementation reported in this study, future efforts are focused on defining a specific role for frailty assessment within clinical care pathways and evaluating its effect on clinical decision making. Based on the findings from this initial cohort, patients identified as potentially frail are referred to an interdisciplinary, preoperative medical home where additional evaluation can be completed. Resources can then be targeted to those patients who are truly frail in an effort to improve their perioperative care. This model of perioperative care has been well-described by other institutions, but patients are often selected for these services based on age or surgeon

discretion[20,28]. Other programs are intended for all patients which may limit the depth and intensity of interventions offered[29]. We hypothesize that routine use of the RAI may address the over- and underutilization of these resources inherent in generalized and/or discretionary implementation strategies.

There are limitations to this study inherent to the pragmatic nature of its design. Because the RAI questionnaire was completed by patients and reviewed by a variety of clinical staff, it is possible that some scores were the product of inaccurate answers to the component questions. Despite this fact, our data suggest the RAI displays more than adequate discrimination and calibration. Though use of dedicated staff to collect the information from each patient may improve accuracy, it is likely this would have a significant impact on the ability to widely screen patients due to a negative impact on clinical workflow. It is also uncertain if any associated incremental improvements in accuracy of measuring the RAI would justify the necessary investment of time, personnel, and other resources. This study is also limited in that it does not address whether interventions based on this information translate to improved outcomes or reduced costs. This is the primary goal of future work involving the RAI. Finally, while UPMC represents a large, multi-hospital health system serving a diverse patient population, the generalizability of our findings to health systems serving other patient populations in other geographies will need to be confirmed in future work.

Frail patients present a unique challenge for the healthcare systems that treat them and identification of any mechanisms which can facilitate the delivery of high-value, patient-centered surgical care should be a priority. In this study, we not only confirm the validity of the RAI as a frailty assessment associated with clinically relevant surgical outcomes, but also demonstrate the feasibility of its implementation as a patient reported measure within the existing infrastructure and clinical workflow of a multi-hospital healthcare system. This effort may provide a roadmap for other institutions interested in implementing similar programs.

References

1. US Census Bureau. Projections of the population by selected age groups and sex for the United States: 2015-2060.
2. Etzioni D a, Liu JH, Maggard M a, et al. The aging population and its impact on the surgery workforce. *Ann Surg*. 2003;238:170–7.
3. Kwok AC, Semel ME, Lipsitz SR, et al. The intensity and variation of surgical care at the end of life: A retrospective cohort study. *Lancet*. 2011;378:1408–1413.
4. Makary MA, Segev DL, Pronovost PJ, et al. Frailty as a predictor of surgical outcomes in older patients. *J Am Coll Surg*. 2010;210:901–8.
5. Robinson TN, Eiseman B, Wallace JI, et al. Redefining geriatric preoperative assessment using frailty, disability and co-morbidity. *Ann Surg*. 2009;250:449–55.
6. Mcisaac DI, Bryson GL, van Walraven C. The impact of frailty on one year post-operative mortality following major elective non-cardiac surgery: a population-based cohort study. *Ann Surg*. 2015;submitted:1–8.
7. Shah R, Attwood K, Arya S, et al. Association of Frailty With Failure to Rescue After Low-Risk and High-Risk Inpatient Surgery. *JAMA Surg*. 2018;153:e180214.
8. Hall DE, Arya S, Schmid KK, et al. Development and Initial Validation of the Risk Analysis Index for Measuring Frailty in Surgical Populations. *JAMA Surg*. 2016;15213:1–8.
9. Arya S, Varley P, Youk A, et al. Recalibration and External Validation of the Risk Analysis Index: A Surgical Frailty Assessment Tool. *Ann Surg*. . Epub ahead of print March 19, 2019. DOI: 10.1097/SLA.0000000000003276.
10. Walston J, Bandeen-Roche K, Buta B, et al. Moving Frailty Toward Clinical Practice: NIA Intramural Frailty Science Symposium Summary. *J Am Geriatr Soc*. 2019;67:1559–1564.
11. Ernst KF, Hall DE, Schmid KK, et al. Surgical palliative care consultations over time in relationship to systemwide frailty screening. *JAMA Surg*. 2014;149:1121–6.
12. Hall DE, Arya S, Schmid KK, et al. Association of a Frailty Screening Initiative With Postoperative Survival at 30, 180, and 365 Days. *JAMA Surg*. 2016;378:1408–1413.
13. Harris PA, Taylor R, Thielke R, et al. Research electronic data capture (REDCap)—A metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform*. 2009;42:377–381.
14. Bilimoria KY, Liu Y, Paruch JL, et al. Development and evaluation of the universal ACS NSQIP surgical risk calculator: a decision aid and informed consent tool for patients and surgeons. *J Am Coll Surg*. 2013;217:833-42–3.
15. Kaplan EL, Meier P. Nonparametric Estimation from Incomplete Observations. *J Am Stat Assoc*. 1958;53:457–481.
16. Nagelkerke NJD. A note on a general definition of the coefficient of determination. *Biometrika*. 1991;78:691–692.

17. Akaike H. A new look at the statistical model identification. *IEEE Trans Automat Contr*. 1974;19:716–723.

18. van Walraven C, McAlister FA, Bakal JA, et al. External validation of the Hospital-patient One-year Mortality Risk (HOMR) model for predicting death within 1 year after hospital admission. *CMAJ*. 2015;187:725–33.

19. DeLong ER, DeLong DM, Clarke-Pearson DL. Comparing the Areas under Two or More Correlated Receiver Operating Characteristic Curves: A Nonparametric Approach. *Biometrics*. 1988;44:837.

20. Katlic MR, Coleman JA, Khan K, et al. Sinai Abbreviated Geriatric Evaluation: Development and Validation of a Practical Test. *Ann Surg*. 2019;269:177–183.

21. Kim SW, Han HS, Jung HW, et al. Multidimensional frailty score for the prediction of postoperative mortality risk. *JAMA Surg*. 2014;149:633–640.

22. Dale W, Hemmerich J, Kamm A, et al. Geriatric Assessment Improves Prediction of Surgical Outcomes in Older Adults Undergoing Pancreaticoduodenectomy. *Ann Surg*. 2014;259:960–965.

23. McIsaac DI, Taljaard M, Bryson GL, et al. Frailty as a Predictor of Death or New Disability After Surgery: A Prospective Cohort Study. *Ann Surg*. . Epub ahead of print July 24, 2018. DOI: 10.1097/SLA.0000000000002967.

24. Robinson TN, Wu DS, Stiegmann G V., et al. Frailty predicts increased hospital and six-month healthcare cost following colorectal surgery in older adults. *Am J Surg*. 2011;202:511–514.

25. Wilkes JG, Evans JL, Prato BS, et al. Frailty Cost: Economic Impact of Frailty in the Elective Surgical Patient. *J Am Coll Surg*. 2019;228:861–870.

26. van Kempen JAL, Schers HJ, Philp I, et al. Predictive validity of a two-step tool to map frailty in primary care. *BMC Med*. 2015;13:287.

27. Glajchen M, Lawson R, Homel P, et al. A rapid two-stage screening protocol for palliative care in the emergency department: a quality improvement initiative. *J Pain Symptom Manage*. 2011;42:657–62.

28. Barberan-Garcia A, Ubré M, Roca J, et al. Personalised Prehabilitation in High-risk Patients Undergoing Elective Major Abdominal Surgery. *Ann Surg*. 2018;267:50–56.

29. Howard R, Yin YS, McCandless L, et al. Taking Control of Your Surgery: Impact of a Prehabilitation Program on Major Abdominal Surgery. *J Am Coll Surg*. 2019;228:72–80.

Figures

Figure 1. Compliance with RAI Screening. Nine programs were assessed with compliance for the recommendation to screen patients using the RAI. Compliance was determined by acknowledgement of an EPIC Best Practice Alert. The system-wide compliance is shown, as well as individual data for the top and bottom two performing programs.

Figure 2. Predicted vs. Observed Mortality by RAI Score. Logistic regression was used to generate predicted 180-day mortality for patients based upon preoperative RAI score. Observed 180-day mortality for patients within each RAI score range was determined and 95% confidence intervals (C.I.) were calculated. To evaluate calibration of the predictions, predicted mortality was plotted (solid line) with observed mortality ± 95% C.I. Overlap between the predicted mortality and CI for observed mortality suggest well-calibrated predictions.

Figure 3. Patient Survival by RAI Score. Kaplan-Meier methods were used to generate survival curves for patients stratified by preoperative RAI score.

Figure 4. Association between RAI and Clinical Outcomes. Cox proportional hazards (mortality) and logistic regression (readmission, LOS, ICU stay) were used to evaluate the association between RAI and patient outcomes. The forest plots present the hazard ratios for mortality and odds ratios for the remaining outcomes by RAI score ranges with 95% confidence intervals, and these demonstrate a dose-dependent association between RAI score. A logarithmic scale was used to preserve visual proportions for ratios above and below 1.

Tables

Table 1. Demographic and clinical characteristics of the NSQIP-eligible cohort

Variable	Category	N (%)
Surgical Service Line	**General Surgery**	3,086 (37.8%)
	Orthopedic Surgery	1,761 (21.5%)
	Urology	593 (7.3%)
	Otolaryngology	555 (6.8%)
	Neurosurgery	552 (6.8%)
	Obstetrics/Gynecology	526 (6.4%)
	Plastic Surgery	379 (4.6%)
	Thoracic Surgery	222 (2.7%)
	Cardiac Surgery	216 (2.6%)
	Other	282 (3.5%)
Gender	**Female**	4,601 (56.3%)
	Male	3,571 (43.7%)
Age at Time of RAI (yrs.)	**< 20**	45 (0.6%)
	20-24	178 (2.2%)
	25-29	299 (3.7%)
	30-34	358 (4.4%)
	35-39	447 (5.5%)
	40-44	489 (6.0%)
	45-49	678 (8.3%)
	50-54	777 (9.5%)
	55-59	939 (11.5%)
	60-64	1,009 (12.3%)
	65-69	1,101 (13.5%)
	70-74	755 (9.2%)
	75-79	551 (6.7%)
	80-84	337 (4.1%)
	85-89	158 (1.9%)
	≥ 90	51 (0.6%)
	Mean (SD)	*57.5 (16.0)*
Race	**White**	7,000 (85.7%)
	Black	715 (8.7%)
	Other	91 (1.1%)
	Unknown	366 (4.5%)
Ethnicity	**Not Hispanic or Latino**	7,443 (91.1%)
	Hispanic or Latino	39 (0.5%)
	Unknown	690 (8.4%)

BMI	**< 18.5**	115 (1.4%)
	≥ 18.5 & < 25	1,978 (24.2%)
	≥ 25 & < 30	2,639 (32.3%)
	≥ 30 & < 35	1,778 (21.8%)
	≥ 35 & < 40	886 (10.8%)
	≥ 40	689 (8.4%)
	Unknown	87 (1.1%)
	Mean (SD)	*29.8 (7.0)*
Cancer		1,848 (22.6%)
Unintentional Weight Loss		1,046 (12.8%)
Renal Failure		539 (6.6%)
Congestive Heart Failure		539 (2.8%)
Poor Appetite		987 (12.1%)
Dyspnea		590 (7.2%)
Other Living Setting		151 (1.8%)
Cognitive Decline		905 (11.1%)
Activities of Daily Living: Mobility/Locomotion	**0: Independent**	7,064 (86.4%)
	1: Supervised	845 (10.3%)
	2: Limited Assistance	98 (1.2%)
	3: Extensive Assistance	89 (1.1%)
	4: Total Dependence	76 (0.9%)
Activities of Daily Living: Eating	**0: Independent**	7,648 (93.6%)
	1: Supervised	130 (1.6%)
	2: Limited Assistance	311 (3.8%)
	3: Extensive Assistance	24 (0.3%)
	4: Total Dependence	59 (0.7%)
Activities of Daily Living: Toilet Use	**0: Independent**	7,943 (97.2%)
	1: Supervised	115 (1.4%)
	2: Limited Assistance	38 (0.5%)
	3: Extensive Assistance	21 (0.3%)
	4: Total Dependence	55 (0.7%)
Activities of Daily Living: Personal Hygiene	**0: Independent**	7,771 (95.1%)
	1: Supervised	68 (0.8%)
	2: Limited Assistance	92 (1.1%)
	3: Extensive Assistance	163 (2.0%)
	4: Total Dependence	78 (1.0%)
RAI-C	**0-4**	282 (3.5%)
	5-9	544 (6.7%)
	10-14	1,003 (12.3%)
	15-19	1,370 (16.8%)

	20-24	1,495 (18.3%)
	25-29	895 (11.0%)
	30-34	1,095 (13.4%)
	35-39	855 (10.5%)
	40-44	355 (4.3%)
	45-49	166 (2.0%)
	≥ 50	112 (1.4%)
	Mean (SD)	*23.6 (11.2)*
Mortality within 30 Days after Surgery		58 (0.7%)
Mortality within 180 Days after Surgery		213 (2.6%)

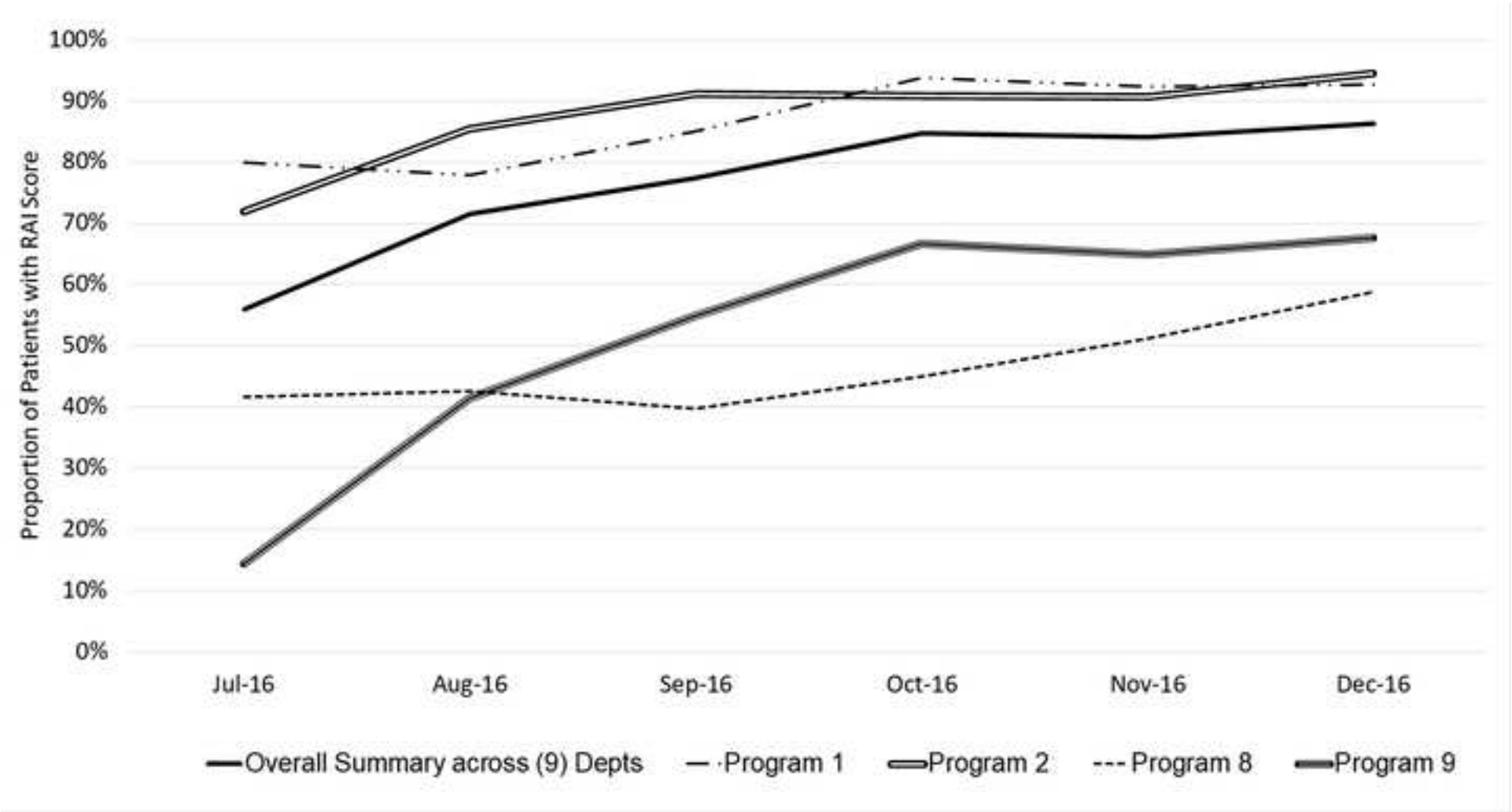
Table 2: Sensitivity, specificity, positive and negative predictive values for 180-day mortality at specified RAI thresholds

RAI-C Threshold	Number of Patients Classified as Frail (% within Total)	Sensitivity	Specificity	Negative Predictive Value	Positive Predictive Value
30	2,583 (31.6%)	76.1%	69.6%	99.1%	6.3%
37	1,085 (13.3%)	54.5%	87.8%	98.6%	10.7%
45	278 (3.4%)	20.2%	97.0%	97.8%	15.5%
53	59 (0.7%)	4.7%	99.4%	97.5%	16.9%

Table 3: Sensitivity, specificity, positive and negative predictive values for secondary outcomes at RAI threshold of 37

Outcome	Number of Occurrences (% within Total IP Visits)	RAI-C Threshold = 37			
		Sensitivity	Specificity	Negative Predictive Value	Positive Predictive Value
30-Day Readmission	341 (9.9%)	31.1%	81.2%	91.5%	15.3%
90-Day Readmission	565 (16.3%)	33.1%	82.5%	86.3%	27.0%
LOS > 7 Days	510 (14.6%)	34.3%	81.9%	88.0%	24.5%
LOS > 14 Days	146 (4.2%)	39.7%	80.4%	96.8%	8.1%
ICU LOS > 0 Days	748 (21.4%)	27.8%	81.6%	80.6%	29.1%
ICU LOS > 4 Days	116 (3.3%)	37.9%	80.2%	97.4%	6.2%
ICU LOS > 7 Days	68 (1.9%)	38.2%	79.9%	98.5%	3.6%

Figure 1



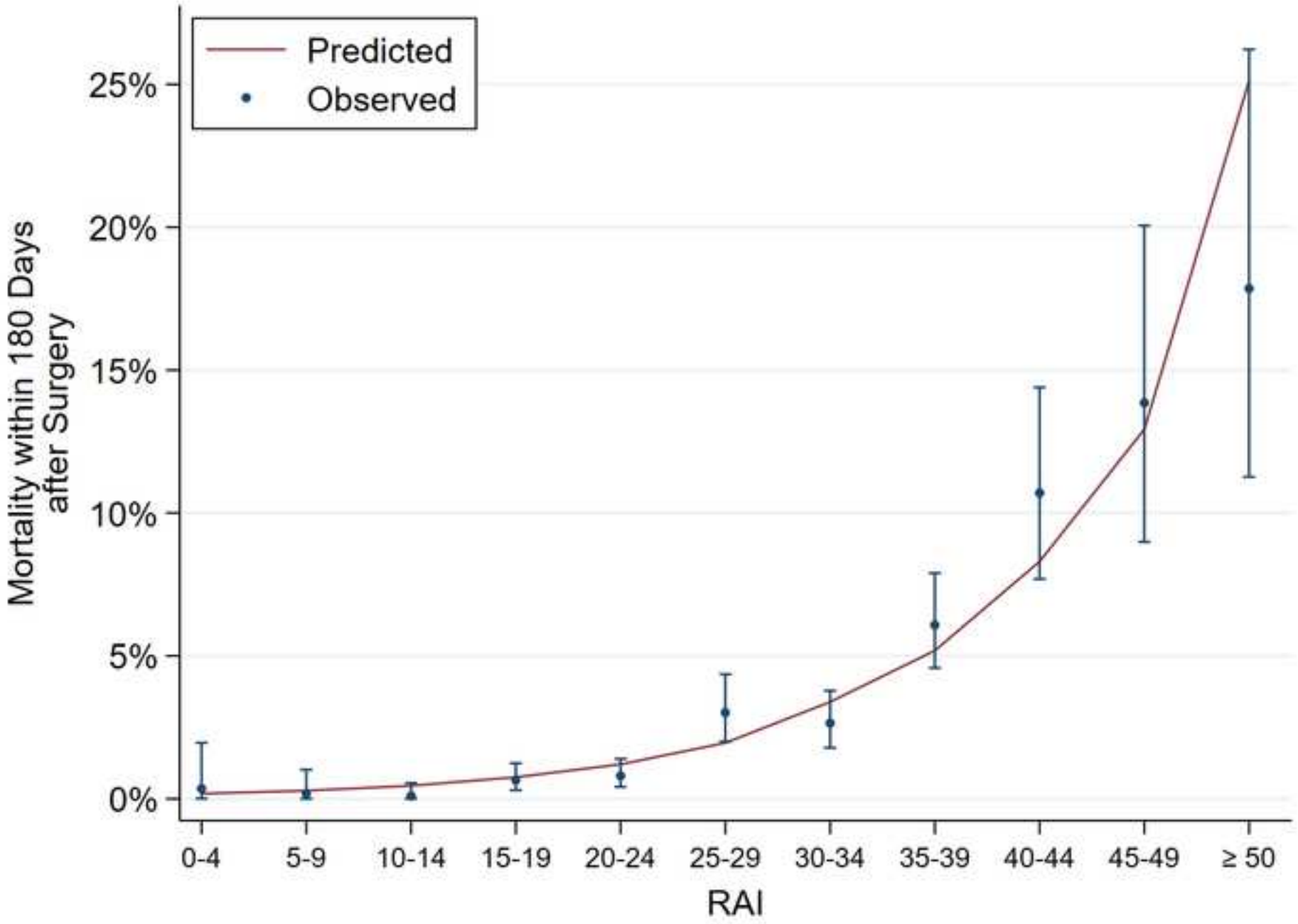


Figure 3

Click here to access/download;Figure;Figure3.jpg

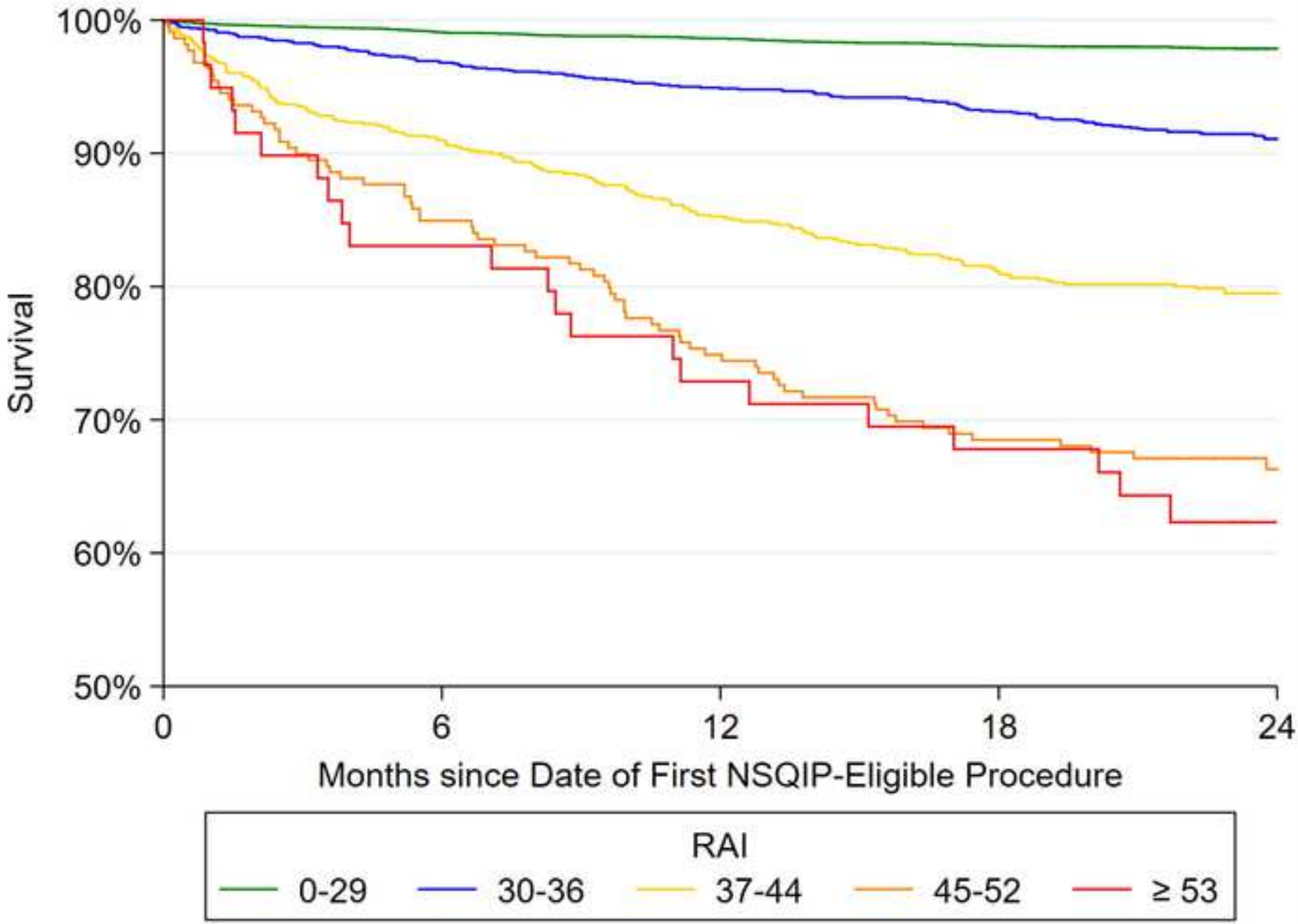
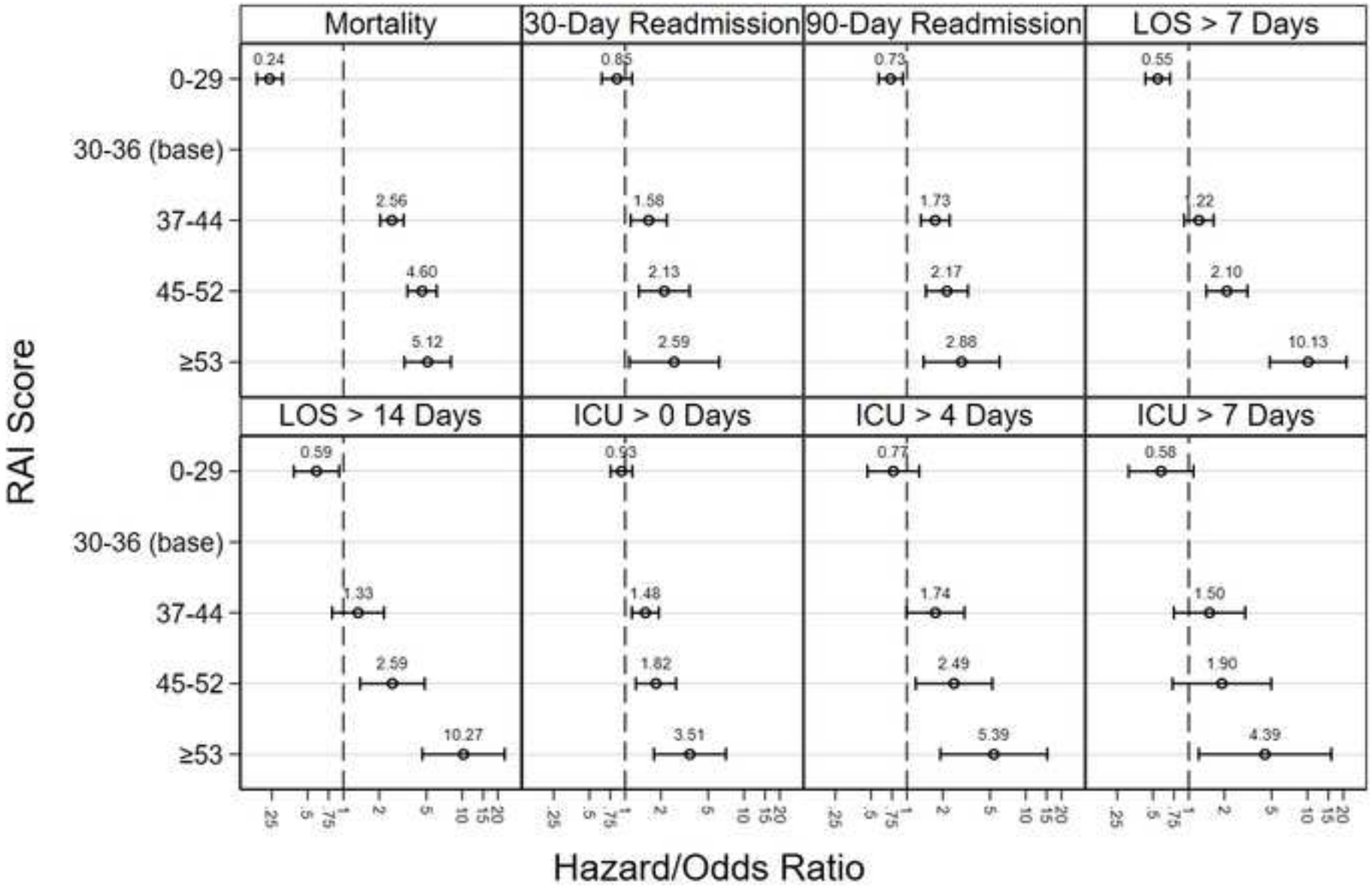
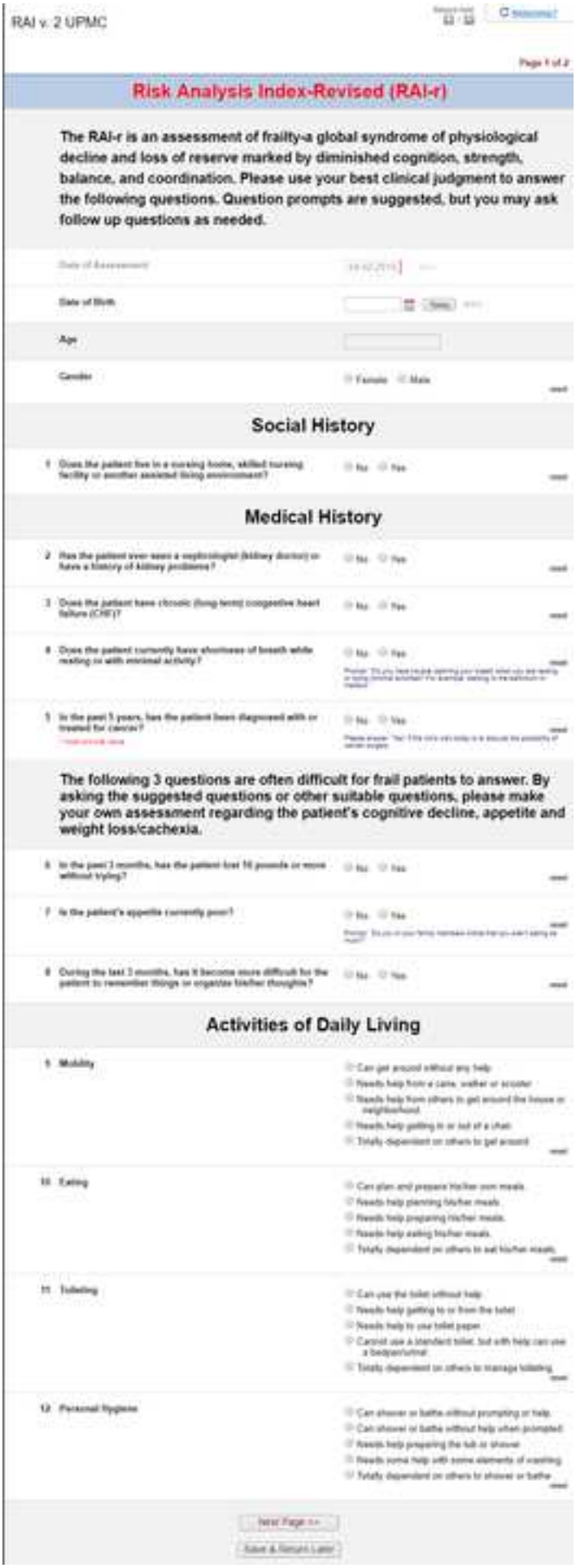


Figure 4



Supplemental Figure 1

Click here to access/download;Miscellaneous document;eFigure1.png



UPMC LIFE CHANGING MEDICINE

RAI Screening Assessment

Patient Identification Label

PRINT NAME LAST	FIRST	M	FORM COMPLETED BY: PATIENT ☐ OTHER _____

Instructions: Please answer the following questions to the best of your ability. Your advocate or companion can help you complete this survey.

Where You Live

1. Do you live in place other than your own home? ☐ No ☐ Yes

If Yes, circle where: Nursing Home Skilled Nursing Facility Assisted Living Other_____

When did you begin living in the place you are currently residing? Less than 3 months 3 months to 1 year Greater than one year ago

Medical Conditions

2. Any kidney failure, kidney not working well, or seeing a kidney doctor (nephrologist)? ☐ No ☐ Yes

If yes circle one: was your nephrologist visit for Kidney stones Other Both Kidney Stones and Other problem

3. Any history of chronic (long-term) congestive heart failure (CHF)? ☐ No ☐ Yes

4. Any shortness of breath when resting? ☐ No ☐ Yes

Do you have trouble catching your breath when resting or doing minimal activities, like walking to the bathroom?

5. In the past five years, have you been diagnosed with or treated for cancer? ☐ No ☐ Yes

Prompt: Please answer "Yes" if the clinic visit today is to discuss the possibility of cancer surgery.

Nutrition

6. Have you lost weight of 10 pounds or more in the past 3 months without trying? ☐ No ☐ Yes

Prompt: Are your clothes feeling looser than in the past?

7. Do you have any loss of appetite?

Prompt: Do you or your family notice that you are not eating as much? ☐ No ☐ Yes

Cognitive

8. During the last 3 months has it become difficult for you to remember things or organize your thoughts? ☐ No ☐ Yes

Activities of Daily Living

9. Getting around (mobility)	☐ Can get around without any help	☐ Needs help from a cane, walker or scooter	☐ Needs Help from others to get around the house or neighborhood	☐ Needs help getting in or out of a chair	☐ Totally dependent on others to get around
10. Eating	☐ Can plan and prepare own meals	☐ Needs help planning meals	☐ Needs help preparing meals	☐ Needs help eating meals	☐ Totally dependent on others to eat meals
11. Toileting	☐ Can use toilet without help	☐ Needs help getting to or from toilet	☐ Needs help to use toilet paper	☐ Cannot use a standard toilet, with help can use bedpan/urinal	☐ Totally dependent on others for toileting
12. Personal hygiene (bathing, hand washing, changing clothes	☐ Can shower or bathe without prompt or help	☐ Can shower or bathe without help when prompted	☐ Needs help preparing the tub or shower	☐ Needs some help with some elements of washing	☐ Totally dependent on others to shower or bathe

Nurse Review:

Rev 07252016

Supplemental Figure 3

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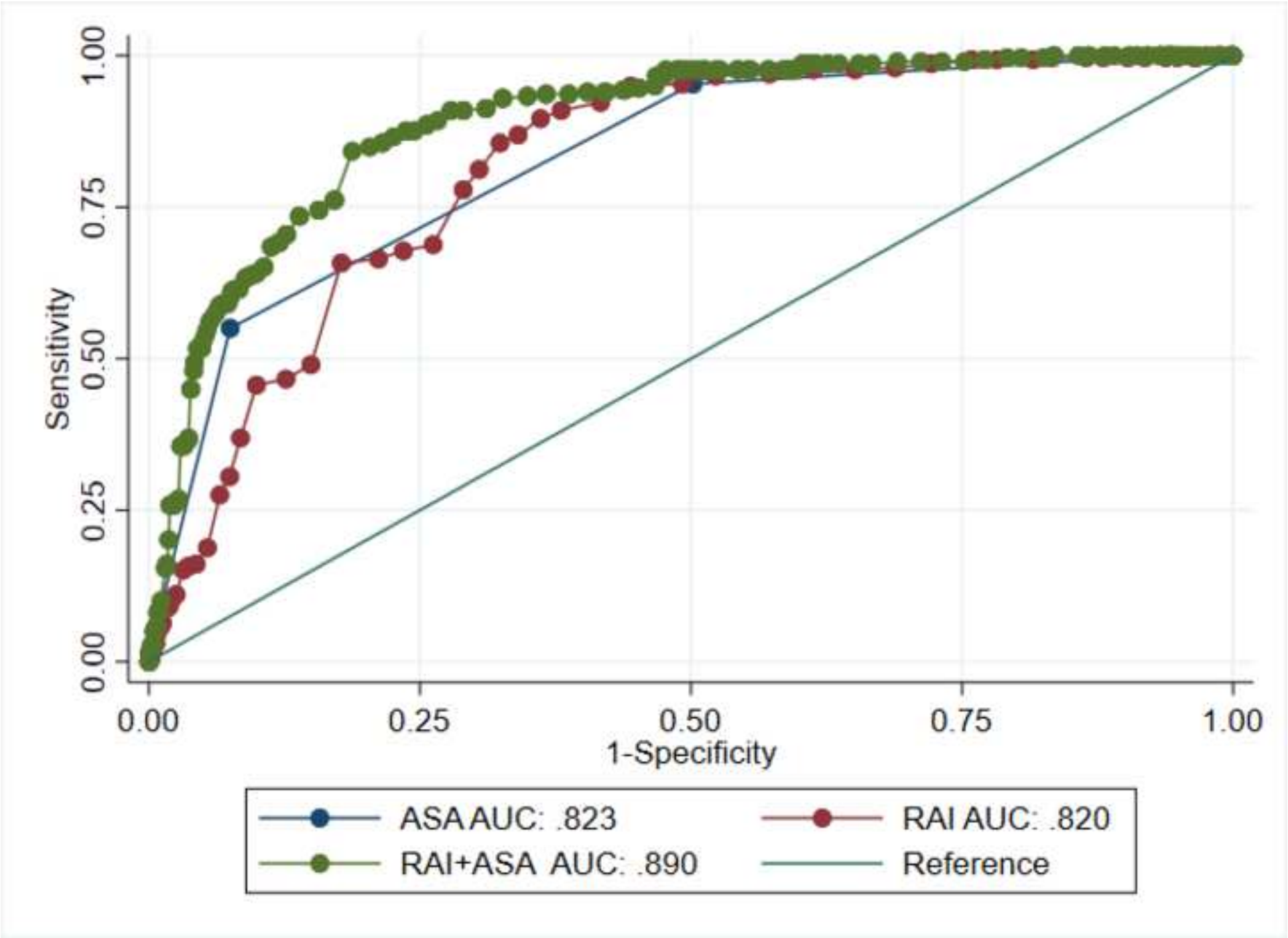

Supplementary Material

Supplementary Figure 1. REDCap RAI Form. A REDCap survey instrument was created to automate scoring. Integration into the EPIC environment allowed pass-through of patient sex and age. The score generated using this form was entered manually into an EPIC flowsheet by clinical staff, and the raw data from the REDCap instrument remained available for linkage to additional clinical data.

Supplementary Figure 2. Patient RAI Form. The original RAI instrument was revised by survey methodologists to allow for completion directly by patients or their surrogate(s). This form was mailed to patients prior to their visit, and completed at home or while waiting for their office visit. Answers were confirmed by clinic staff and entered into the REDCap RAI form to generate the final RAI score.

Supplementary Figure 3. Receiver Operating Curves for RAI and ASA. ROC curves were generated for association between RAI and ASA with 180-day mortality. RAI and ASA had similar C-statistics, but the combination of both predictors led to significant improvement over either instrument alone.

eTable 1. CPT Code Frequencies*

CPT Code	CPT Short Description	N*	Frequency (%)	Cum Frequency (%)
47562	Laparoscopic cholecystectomy	313	3.83	3.83
19301	Partial mastectomy	281	3.44	7.27
29827	Arthroscop rotator cuff repr	253	3.1	10.37
49505	Prp i/hern init reduc >5 yr	188	2.3	12.67
27130	Total hip arthroplasty	161	1.97	14.64
27447	Total knee arthroplasty	160	1.96	16.6
58571	Tlh w/t/o 250 g or less	139	1.7	18.3
22551	Neck spine fuse&remov bel c2	124	1.52	19.82
19125	Excision breast lesion	113	1.38	21.2
60500	Explore parathyroid glands	101	1.24	22.44
11042	Deb subq tissue 20 sq cm/<	100	1.22	23.66
63047	Remove spine lamina 1 lmbr	85	1.04	24.7
49650	Lap ing hernia repair init	80	0.98	25.68
19303	Mast simple complete	77	0.94	26.62
44204	Laparo partial colectomy	77	0.94	27.56
29881	Knee arthroscopy/surgery	76	0.93	28.49
22612	Lumbar spine fusion	72	0.88	29.37
63030	Low back disk surgery	69	0.84	30.21
55866	Laparo radical prostatectomy	61	0.75	30.96
33405	Replacement aortic valve opn	60	0.73	31.69
44207	L colectomy/coloproctostomy	59	0.72	32.41
47120	Partial removal of liver	59	0.72	33.13
36475	Endovenous rf 1st vein	57	0.7	33.83
31599	Larynx surgery procedure	56	0.69	34.52
38724	Removal of lymph nodes neck	56	0.69	35.21

60240	Removal of thyroid	53	0.65	35.86
19302	P-mastectomy w/ln removal	51	0.62	36.48
19357	Breast reconstruction	50	0.61	37.09
22633	Lumbar spine fusion combined	50	0.61	37.7
42826	Removal of tonsils	50	0.61	38.31
49560	Rpr ventral hern init reduc	50	0.61	38.92
49585	Rpr umbil hern reduc > 5 yr	50	0.61	39.53
50240	Partial removal of kidney	48	0.59	40.12
15734	Muscle-skin graft trunk	47	0.58	40.7
32663	Thoracoscopy w/lobectomy	47	0.58	41.28
33533	Cabg arterial single	47	0.58	41.86
55845	Extensive prostate surgery	47	0.58	42.44
35301	Rechanneling of artery	46	0.56	43
19120	Removal of breast lesion	44	0.54	43.54
29888	Knee arthroscopy/surgery	44	0.54	44.08
43281	Lap paraesophag hern repair	44	0.54	44.62
58150	Total hysterectomy	43	0.53	45.15
60220	Partial removal of thyroid	42	0.51	45.66
43644	Lap gastric bypass/roux-en-y	41	0.5	46.16
49652	Lap vent/abd hernia repair	41	0.5	46.66
48150	Partial removal of pancreas	40	0.49	47.15
57425	Laparoscopy surg colpopexy	39	0.48	47.63
58548	Lap radical hyst	37	0.45	48.08
32666	Thoracoscopy w/wedge resect	36	0.44	48.52
43775	Lap sleeve gastrectomy	34	0.42	48.94
49321	Laparoscopy biopsy	34	0.42	49.36
50543	Laparo partial nephrectomy	34	0.42	49.78
63045	Remove spine lamina 1 crvl	34	0.42	50.2

19318	Reduction of large breast	33	0.4	50.6
36818	Av fuse uppr arm cephalic	32	0.39	50.99
44145	Partial removal of colon	32	0.39	51.38
47563	Laparo cholecystectomy/graph	32	0.39	51.77
52235	Cystoscopy and treatment	32	0.39	52.16
61458	Incise skull for brain wound	32	0.39	52.55
19307	Mast mod rad	31	0.38	52.93
25609	Treat fx radial 3+ frag	31	0.38	53.31
27487	Revise/replace knee joint	31	0.38	53.69
29882	Knee arthroscopy/surgery	31	0.38	54.07
58573	Tlh w/t/o uterus over 250 g	31	0.38	54.45
52601	Prostatectomy (turp)	30	0.37	54.82
11044	Deb bone 20 sq cm/<	29	0.35	55.17
29823	Shoulder arthroscopy/surgery	29	0.35	55.52
57288	Repair bladder defect	28	0.34	55.86
49324	Lap insert tunnel ip cath	27	0.33	56.19
69801	Incise inner ear	27	0.33	56.52
11043	Deb musc/fascia 20 sq cm/<	25	0.31	56.83
33430	Replacement of mitral valve	25	0.31	57.14
42415	Excise parotid gland/lesion	25	0.31	57.45
19380	Revise breast reconstruction	24	0.29	57.74
60252	Removal of thyroid	24	0.29	58.03
15830	Exc skin abd	23	0.28	58.31
27134	Revise hip joint replacement	23	0.28	58.59
49205	Exc abd tum over 10 cm	23	0.28	58.87
49653	Lap vent/abd hern proc comp	22	0.27	59.14
29880	Knee arthroscopy/surgery	21	0.26	59.4
44140	Partial removal of colon	21	0.26	59.66

19364	Breast reconstruction	20	0.24	59.9
44970	Laparoscopy appendectomy	20	0.24	60.14
47379	Laparoscope procedure liver	20	0.24	60.38
61510	Removal of brain lesion	20	0.24	60.62
19342	Delayed breast prosthesis	19	0.23	60.85
25111	Remove wrist tendon lesion	19	0.23	61.08
29806	Shoulder arthroscopy/surgery	19	0.23	61.31
44005	Freeing of bowel adhesion	19	0.23	61.54
49203	Exc abd tum 5 cm or less	19	0.23	61.77
49520	Rerepair ing hernia reduce	19	0.23	62
52234	Cystoscopy and treatment	19	0.23	62.23
20926	Removal of tissue for graft	18	0.22	62.45
34802	Endovas aaa repr w/2-p part	18	0.22	62.67
37226	Fem/popl revasc w/stent	18	0.22	62.89
47370	Laparo ablate liver tumor rf	18	0.22	63.11
49587	Rpr umbil hern block > 5 yr	18	0.22	63.33
51595	Remove bladder/revise tract	18	0.22	63.55
52240	Cystoscopy and treatment	18	0.22	63.77
21555	Exc neck les sc < 3 cm	17	0.21	63.98
36819	Av fuse uppr arm basilic	17	0.21	64.19
42821	Remove tonsils and adenoids	17	0.21	64.4
44120	Removal of small intestine	17	0.21	64.61
56620	Partial removal of vulva	17	0.21	64.82
58210	Extensive hysterectomy	17	0.21	65.03
63081	Remove vert body dcmprn crvl	17	0.21	65.24
24341	Repair arm tendon/muscle	16	0.2	65.44
44625	Repair bowel opening	16	0.2	65.64
49654	Lap inc hernia repair	16	0.2	65.84

50230	Removal kidney open radical	16	0.2	66.04
50949	Laparoscope proc ureter	16	0.2	66.24
23472	Reconstruct shoulder joint	15	0.18	66.42
38745	Remove armpit lymph nodes	15	0.18	66.6
47600	Removal of gallbladder	15	0.18	66.78
48140	Partial removal of pancreas	15	0.18	66.96
60650	Laparoscopy adrenalectomy	15	0.18	67.14
25447	Repair wrist joints	14	0.17	67.31
29879	Knee arthroscopy/surgery	14	0.17	67.48
32669	Thoracoscopy remove segment	14	0.17	67.65
44205	Lap colectomy part w/ileum	14	0.17	67.82
49204	Exc abd tum over 5 cm	14	0.17	67.99
60210	Partial thyroid excision	14	0.17	68.16
60254	Extensive thyroid surgery	14	0.17	68.33
26145	Tendon excision palm/finger	13	0.16	68.49
27132	Total hip arthroplasty	13	0.16	68.65
32480	Partial removal of lung	13	0.16	68.81
37221	Iliac revasc w/stent	13	0.16	68.97
38570	Laparoscopy lymph node biop	13	0.16	69.13
19361	Breast reconstr w/lat flap	12	0.15	69.28
20902	Removal of bone for graft	12	0.15	69.43
29877	Knee arthroscopy/surgery	12	0.15	69.58
31365	Removal of larynx	12	0.15	69.73
33999	Cardiac surgery procedure	12	0.15	69.88
46040	Incision of rectal abscess	12	0.15	70.03
49565	Rerepair ventrl hern reduce	12	0.15	70.18
51596	Remove bladder/create pouch	12	0.15	70.33
61885	Insrt/redo neurostim 1 array	12	0.15	70.48

63042	Laminotomy single lumbar	12	0.15	70.63
15750	Neurovascular pedicle flap	11	0.13	70.76
21556	Exc neck tum deep < 5 cm	11	0.13	70.89
24075	Exc arm/elbow les sc < 3 cm	11	0.13	71.02
25607	Treat fx rad extra-articul	11	0.13	71.15
27245	Treat thigh fracture	11	0.13	71.28
27829	Treat lower leg joint	11	0.13	71.41
29828	Arthroscopy biceps tenodesis	11	0.13	71.54
33534	Cabg arterial two	11	0.13	71.67
33860	Ascending aortic graft	11	0.13	71.8
43280	Laparoscopy fundoplasty	11	0.13	71.93
43659	Laparoscope proc stom	11	0.13	72.06
44180	Lap enterolysis	11	0.13	72.19
44626	Repair bowel opening	11	0.13	72.32
49561	Rpr ventral hern init block	11	0.13	72.45
57522	Conization of cervix	11	0.13	72.58
15757	Free skin flap microvasc	10	0.12	72.7
19316	Suspension of breast	10	0.12	72.82
25608	Treat fx rad intra-articul	10	0.12	72.94
26123	Release palm contracture	10	0.12	73.06
26735	Treat finger fracture each	10	0.12	73.18
29824	Shoulder arthroscopy/surgery	10	0.12	73.3
29916	Hip arthro w/labral repair	10	0.12	73.42
35556	Art byp grft fem-popliteal	10	0.12	73.54
37224	Fem/popl revas w/tla	10	0.12	73.66
37228	Tib/per revasc w/tla	10	0.12	73.78
47125	Partial removal of liver	10	0.12	73.9
50548	Laparo remove w/ureter	10	0.12	74.02

54530	Removal of testis	10	0.12	74.14
58570	Tlh uterus 250 g or less	10	0.12	74.26

* CPT codes with frequency <10 have been omitted to prevent identification of individual patients.

eTable 2: Predictive ability of RAI by gender

Outcome	Gender	C-Statistic (95% C.I.)	AIC	Max. R^2	Absolute Difference: Median (IQR)	Overlap	p
Mortality within 30 Days after Admission	**Female [N = 4,601]**	0.739 (0.654 - 0.824)	290.18	0.0563	0.6 (0.2 - 3.7)	98.4%	0.914
	Male [N = 3,571]	0.810 (0.734 - 0.885)	348.71	0.1143	0.9 (0.3 - 5.2)	96.8%	
	Total [N = 8,172]	0.788 (0.731 - 0.845)	634.89	0.0884	0.6 (0.2 - 3.7)	97.1%	
Mortality within 180 Days after Admission	**Female [N = 4,601]**	0.812 (0.774 - 0.850)	845.55	0.1491	1.5 (0.3 - 7.6)	98.4%	0.224
	Male [N = 3,571]	0.815 (0.776 - 0.854)	859.93	0.1616	2.0 (0.4 - 7.6)	98.4%	
	Total [N = 8,172]	0.815 (0.788 - 0.842)	1,701.48	0.1551	0.9 (0.4 - 4.0)	95.6%	

eTable 3. Sensitivity, specificity, positive and negative predictive values for 180-day mortality at each RAI threshold

RAI-C Threshold	Number of Patients (% within Total)	Number of 180-Day Mortalities (% within RAI-C)	Number of Patients Classified as Frail (% within Total)	Sensitivity	Specificity	Positive Predictive Value	Negative Predictive Value	Predicted 180-Day Mortality Rate
0	19 (0.2%)	0 (0%)	8,172 (100%)	100%	0%	2.6%	N/A	0.1%
1	76 (0.9%)	0 (0%)	8,153 (99.8%)	100%	0.2%	2.6%	100%	0.1%
2	1 (0.0%)	0 (0%)	8,077 (98.8%)	100%	1.2%	2.6%	100%	0.2%
3	14 (0.2%)	0 (0%)	8,076 (98.8%)	100%	1.2%	2.6%	100%	0.2%
4	172 (2.1%)	1 (0.6%)	8,062 (98.7%)	100%	1.4%	2.6%	100%	0.2%
5	17 (0.2%)	0 (0%)	7,890 (96.5%)	99.5%	3.5%	2.7%	99.6%	0.2%
6	130 (1.6%)	0 (0%)	7,873 (96.3%)	99.5%	3.7%	2.7%	99.7%	0.2%
7	86 (1.1%)	0 (0%)	7,743 (94.8%)	99.5%	5.4%	2.7%	99.8%	0.3%
8	180 (2.2%)	1 (0.6%)	7,657 (93.7%)	99.5%	6.5%	2.8%	99.8%	0.3%
9	131 (1.6%)	0 (0%)	7,477 (91.5%)	99.1%	8.7%	2.8%	99.7%	0.3%
10	198 (2.4%)	0 (0%)	7,346 (89.9%)	99.1%	10.4%	2.9%	99.8%	0.4%
11	133 (1.6%)	0 (0%)	7,148 (87.5%)	99.1%	12.8%	3.0%	99.8%	0.4%

12	263 (3.2%)	0 (0%)	7,015 (85.8%)	99.1%	14.5%	3.0%	99.8%	0.4%
13	140 (1.7%)	1 (0.7%)	6,752 (82.6%)	99.1%	17.8%	3.1%	99.9%	0.5%
14	269 (3.3%)	0 (0%)	6,612 (80.9%)	98.6%	19.6%	3.2%	99.8%	0.5%
15	202 (2.5%)	1 (0.5%)	6,343 (77.6%)	98.6%	22.9%	3.3%	99.8%	0.6%
16	285 (3.5%)	3 (1.1%)	6,141 (75.1%)	98.1%	25.5%	3.4%	99.8%	0.7%
17	275 (3.4%)	3 (1.1%)	5,856 (71.7%)	96.7%	29.0%	3.5%	99.7%	0.7%
18	301 (3.7%)	2 (0.7%)	5,581 (68.3%)	95.3%	32.4%	3.6%	99.6%	0.8%
19	307 (3.8%)	0 (0%)	5,280 (64.6%)	94.4%	36.2%	3.8%	99.6%	0.9%
20	321 (3.9%)	2 (0.6%)	4,973 (60.9%)	94.4%	40.0%	4.0%	99.6%	1.0%
21	364 (4.5%)	2 (0.5%)	4,652 (56.9%)	93.4%	44.1%	4.3%	99.6%	1.1%
22	246 (3.0%)	2 (0.8%)	4,288 (52.5%)	92.5%	48.6%	4.6%	99.6%	1.2%
23	349 (4.3%)	2 (0.6%)	4,042 (49.5%)	91.5%	51.7%	4.8%	99.6%	1.3%
24	215 (2.6%)	4 (1.9%)	3,693 (45.2%)	90.6%	56.0%	5.2%	99.6%	1.5%
25	274 (3.4%)	5 (1.8%)	3,478 (42.6%)	88.7%	58.7%	5.4%	99.5%	1.6%
26	158 (1.9%)	3 (1.9%)	3,204 (39.2%)	86.4%	62.1%	5.7%	99.4%	1.8%
27	181 (2.2%)	8 (4.4%)	3,046 (37.3%)	85.0%	64.0%	5.9%	99.4%	2.0%
28	133 (1.6%)	4 (3.0%)	2,865 (35.1%)	81.2%	66.2%	6.0%	99.2%	2.2%

29	149 (1.8%)	7 (4.7%)	2,732 (33.4%)	79.3%	67.8%	6.2%	99.2%	2.4%
30	125 (1.5%)	6 (4.8%)	2,583 (31.6%)	76.1%	69.6%	6.3%	99.1%	2.7%
31	235 (2.9%)	4 (1.7%)	2,458 (30.1%)	73.2%	71.1%	6.3%	99.0%	3.0%
32	244 (3.0%)	7 (2.9%)	2,223 (27.2%)	71.4%	74.0%	6.8%	99.0%	3.3%
33	187 (2.3%)	7 (3.7%)	1,979 (24.2%)	68.1%	77.0%	7.3%	98.9%	3.6%
34	304 (3.7%)	5 (1.6%)	1,792 (21.9%)	64.8%	79.2%	7.7%	98.8%	4.0%
35	228 (2.8%)	7 (3.1%)	1,488 (18.2%)	62.4%	83.0%	8.9%	98.8%	4.4%
36	175 (2.1%)	10 (5.7%)	1,260 (15.4%)	59.2%	85.8%	10.0%	98.7%	4.8%
37	203 (2.5%)	4 (2.0%)	1,085 (13.3%)	54.5%	87.8%	10.7%	98.6%	5.3%
38	142 (1.7%)	14 (9.9%)	882 (10.8%)	52.6%	90.3%	12.7%	98.6%	5.8%
39	107 (1.3%)	17 (15.9%)	740 (9.1%)	46.0%	91.9%	13.2%	98.5%	6.4%
40	85 (1.0%)	11 (12.9%)	633 (7.7%)	38.0%	93.1%	12.8%	98.2%	7.1%
41	84 (1.0%)	12 (14.3%)	548 (6.7%)	32.9%	94.0%	12.8%	98.1%	7.7%
42	93 (1.1%)	11 (11.8%)	464 (5.7%)	27.2%	94.9%	12.5%	98.0%	8.5%
43	49 (0.6%)	2 (4.1%)	371 (4.5%)	22.1%	95.9%	12.7%	97.9%	9.3%
44	44 (0.5%)	2 (4.5%)	322 (3.9%)	21.1%	96.5%	14.0%	97.9%	10.2%
45	57 (0.7%)	7 (12.3%)	278 (3.4%)	20.2%	97.0%	15.5%	97.8%	11.2%

46	31 (0.4%)	5 (16.1%)	221 (2.7%)	16.9%	97.7%	16.3%	97.8%	12.2%
47	29 (0.4%)	4 (13.8%)	190 (2.3%)	14.6%	98.0%	16.3%	97.7%	13.4%
48	27 (0.3%)	3 (11.1%)	161 (2.0%)	12.7%	98.3%	16.8%	97.7%	14.6%
49	22 (0.3%)	4 (18.2%)	134 (1.6%)	11.3%	98.6%	17.9%	97.6%	15.9%
50	17 (0.2%)	3 (17.6%)	112 (1.4%)	9.4%	98.8%	17.9%	97.6%	17.3%
51	21 (0.3%)	4 (19.0%)	95 (1.2%)	8.0%	99.0%	17.9%	97.6%	18.8%
52	15 (0.2%)	3 (20.0%)	74 (0.9%)	6.1%	99.2%	17.6%	97.5%	20.4%
53	12 (0.1%)	0 (0%)	59 (0.7%)	4.7%	99.4%	16.9%	97.5%	22.1%
54	12 (0.1%)	3 (25.0%)	47 (0.6%)	4.7%	99.5%	21.3%	97.5%	23.8%
55	7 (0.1%)	2 (28.6%)	35 (0.4%)	3.3%	99.6%	20.0%	97.5%	25.7%
56	4 (0.0%)	1 (25.0%)	28 (0.3%)	2.3%	99.7%	17.9%	97.4%	27.7%
57	0 (0%)	0 (N/A)	24 (0.3%)	1.9%	99.7%	16.7%	97.4%	29.8%
58	6 (0.1%)	2 (33.3%)	24 (0.3%)	1.9%	99.7%	16.7%	97.4%	31.9%
59	4 (0.0%)	0 (0%)	18 (0.2%)	0.9%	99.8%	11.1%	97.4%	34.2%
60	2 (0.0%)	1 (50.0%)	14 (0.2%)	0.9%	99.8%	14.3%	97.4%	36.5%
61	5 (0.1%)	1 (20.0%)	12 (0.1%)	0.5%	99.9%	8.3%	97.4%	38.9%
62	1 (0.0%)	0 (0%)	7 (0.1%)	0%	99.9%	0%	97.4%	41.3%
63	1 (0.0%)	0 (0%)	6 (0.1%)	0%	99.9%	0%	97.4%	43.8%
64	0 (0%)	0 (N/A)	5 (0.1%)	0%	99.9%	0%	97.4%	46.3%
65	1 (0.0%)	0 (0%)	5 (0.1%)	0%	99.9%	0%	97.4%	48.8%
66	0 (0%)	0 (N/A)	4 (0.0%)	0%	99.9%	0%	97.4%	51.3%
67	1 (0.0%)	0 (0%)	4 (0.0%)	0%	99.9%	0%	97.4%	53.8%
68	0 (0%)	0 (N/A)	3 (0.0%)	0%	100.0%	0%	97.4%	56.4%
69	0 (0%)	0 (N/A)	3 (0.0%)	0%	100.0%	0%	97.4%	58.8%
70	1 (0.0%)	0 (0%)	3 (0.0%)	0%	100.0%	0%	97.4%	61.3%

71	0 (0%)	0 (N/A)	2 (0.0%)	0%	100.0%	0%	97.4%	63.6%
72	1 (0.0%)	0 (0%)	2 (0.0%)	0%	100.0%	0%	97.4%	65.9%
73	1 (0.0%)	0 (0%)	1 (0.0%)	0%	100.0%	0%	97.4%	68.2%
74	0 (0%)	0 (N/A)	0 (0%)	0%	100%	N/A	97.4%	70.3%
75	0 (0%)	0 (N/A)	0 (0%)	0%	100%	N/A	97.4%	72.4%
76	0 (0%)	0 (N/A)	0 (0%)	0%	100%	N/A	97.4%	74.4%
77	0 (0%)	0 (N/A)	0 (0%)	0%	100%	N/A	97.4%	76.2%
78	0 (0%)	0 (N/A)	0 (0%)	0%	100%	N/A	97.4%	78.0%
79	0 (0%)	0 (N/A)	0 (0%)	0%	100%	N/A	97.4%	79.7%
80	0 (0%)	0 (N/A)	0 (0%)	0%	100%	N/A	97.4%	81.3%
81	0 (0%)	0 (N/A)	0 (0%)	0%	100%	N/A	97.4%	82.8%

eTable 4. Hazard and Odds Ratios for Clinical Outcomes

Outcome	RAI 0-29 vs. 30-36		RAI 37-44 vs. 30-36		RAI 45-52 vs. 30-36		RAI ≥ 53 vs. 30-36		Harrell's C-Index
	Hazard Ratio (95% C.I.)	p	Hazard Ratio (95% C.I.)	p	Hazard Ratio (95% C.I.)	p	Hazard Ratio (95% C.I.)	p	
Mortality	0.239 (0.187, 0.307)	< 0.001	2.561 (2.037, 3.219)	< 0.001	4.597 (3.460, 6.106)	< 0.001	5.120 (3.259, 8.044)	< 0.001	0.810

Outcome	RAI 0-29 vs. 30-36		RAI 37-44 vs. 30-36		RAI 45-52 vs. 30-36		RAI ≥ 53 vs. 30-36		C-Index
	Odds Ratio (95% C.I.)	p	Odds Ratio (95% C.I.)	p	Odds Ratio (95% C.I.)	p	Odds Ratio (95% C.I.)	p	
30-Day Readmission	0.853 (0.635, 1.145)	0.290	1.580 (1.113, 2.243)	0.011	2.135 (1.305, 3.493)	0.003	2.587 (1.083, 6.179)	0.032	0.595
90-Day Readmission	0.729 (0.577, 0.923)	0.008	1.731 (1.311, 2.286)	< 0.001	2.171 (1.445, 3.263)	< 0.001	2.885 (1.383, 6.022)	0.005	0.615
LOS > 7 Days	0.549 (0.432, 0.697)	< 0.001	1.219 (0.916, 1.622)	0.174	2.095 (1.407, 3.121)	< 0.001	10.125 (4.814, 21.298)	< 0.001	0.648
LOS > 14 Days	0.594 (0.383, 0.923)	0.021	1.329 (0.804, 2.199)	0.268	2.585 (1.383, 4.830)	0.003	10.275 (4.622, 22.843)	< 0.001	0.639
ICU LOS > 0 Days	0.931 (0.754, 1.149)	0.506	1.479 (1.138, 1.921)	0.003	1.819 (1.232, 2.684)	0.003	3.508 (1.747, 7.043)	< 0.001	0.586
ICU LOS > 4 Days	0.768 (0.465, 1.270)	0.304	1.737 (0.989, 3.050)	0.055	2.492 (1.187, 5.230)	0.016	5.390 (1.913, 15.189)	0.001	0.639
ICU LOS > 7 Days	0.585 (0.312, 1.097)	0.094	1.498 (0.750, 2.992)	0.253	1.904 (0.732, 4.949)	0.187	4.391 (1.215, 15.867)	0.024	0.643

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