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The Rothman Index Is Associated With Postdischarge Adverse Events After Hip Fracture Surgery in Geriatric Patients

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Abstract

Background The Rothman Index is a comprehensive measure of overall patient status in the inpatient setting already in use at many medical centers. It ranges from 100 (best score) to -91 (worst score) and is calculated based on 26 variables encompassing vital signs, routine laboratory values, and organ system assessments from nursing rounds from the electronic medical record. Past research has shown an association of Rothman Index with complications, readmission, and death in certain populations, but it has not been evaluated in geriatric patients with hip fractures, a potentially vulnerable patient population.

Questions/purposes (1) Is there an association between Rothman Index scores and postdischarge adverse events in a population aged 65 years and older with hip fractures? (2) What is the discriminative ability of Rothman Index scores in determining which patients will or will not experience these adverse events? (3) Are there Rothman Index thresholds associated with increased incidence of postdischarge adverse outcomes?

Methods One thousand two hundred fourteen patients aged 65 years and older who underwent hip fracture surgery at an academic medical center between 2013 and 2016 were identified. Demographic and comorbidity characteristics were characterized, and 30-day postdischarge adverse events were calculated. The associations between a 10-unit change in Rothman Index scores and

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postdischarge adverse events, mortality, and readmission were determined. American Society of Anesthesiologists (ASA) class was used as a measure of comorbidity because prior research has shown its performance to be equivalent or superior to that of calculated comorbidity measures in this data set. We assessed the ability of Rothman Index scores to determine which patients experienced adverse events. Finally, Rothman Index thresholds were assessed for an association with increased incidence of postdischarge adverse outcomes.

Results We found a strong association between Rothman Index scores and postdischarge adverse events (lowest score: odds ratio [OR] = 1.29 [1.18-1.41], $p < 0.001$; latest score: OR = 1.37 [1.24-1.52], $p < 0.001$) after controlling for age, sex, body mass index, ASA class, and surgical procedure performed. The discriminative ability of lowest and latest Rothman Index scores was better than those of age, sex, and ASA class for any adverse event (lowest value: area under the curve [AUC] = 0.641; 95% confidence interval [CI], 0.601-0.681; latest value: AUC = 0.640; 95% CI, 0.600-0.680); age (0.534; 95% CI, 0.493-0.575, $p < 0.001$ for both), male sex (0.552; 95% CI, 0.518-0.585, $p = 0.001$ for both), and ASA class (0.578; 95% CI, 0.542-0.614; $p = 0.004$ for lowest Rothman Index, $p = 0.006$ for latest Rothman Index). There was never a difference when comparing lowest Rothman Index value and latest Rothman Index value for any of the outcomes (Table 5). Patients experienced increased rates of postdischarge adverse events and mortality with a lowest Rothman Index of ≤ 35 ($p < 0.05$) or latest Rothman Index of ≤ 55 ($p < 0.05$).

Conclusions The Rothman Index provides an objective method of assessing perioperative risk in the setting of hip fracture surgery in patients older than age 65 years and is more accurate than demographic measures or ASA class. Furthermore, there are Rothman Index thresholds that can be used to identify patients at increased risk of complications. Physicians can use this tool to monitor the condition of patients with hip fracture, recognize patients at high risk of adverse events to consider changing their plan of care, and counsel patients and families. Further investigation is needed to determine whether interventions based on Rothman Index values contribute to improved outcomes or value of hip fracture care.

Level of Evidence Level II, diagnostic study.

Introduction

Hip fractures pose a major source of morbidity and mortality for elderly patients. More than 250,000 geriatric patients per year are admitted to hospitals in the United States with hip fractures [6] with a 1-year mortality rate ranging from 20% to 35% [4, 6, 10, 32]. Additionally, hip fractures in geriatric patients impose a substantial financial strain on the healthcare system with annual costs of approximately USD 10 to 15 billion per year in the United States alone [7, 10]. Current population trends suggest a growing burden of such injuries, because projections suggest that the population ≥ 65 years will increase 80% by 2050 [8], whereas the population ≥ 85 years will triple in the same period [23]. The increased push for accountability of hospitals and physicians necessitates cost reduction strategies, including accurate identification of patients with high risk of postdischarge complications.

The majority of studies examining predictors for adverse events and readmission after hip fracture focuses on preoperative demographic, comorbidity, and functional status factors [1, 3, 12, 14, 16, 17, 19, 27]. However, few studies have studied the acute perioperative period to identify factors associated with adverse outcomes at key decision points after surgery (ie, discharge). One promising measure of patient condition is the Rothman Index (PeraHealth, Charlotte, NC, USA) [26]. The Rothman Index enables real-time delineation of patient condition independent of diagnosis or acuity level. The Rothman Index score is objective, regularly updated, and calculated from a patient's electronic medical record based on vital signs, laboratory values, and yes/no nursing assessments of organ systems (Table 1). Scores are calculated from a proprietary formula and range from 100 to -91 with 100 suggesting good health. Points are deducted as the patient's values deviate from reference ranges [26]. Therefore, the lower the Rothman Index score, the sicker the patient.

Table 1. Variables contributing to the Rothman Index

Vital signs	Laboratory values	Nursing assessments
Temperature	White blood cell count	Respiratory
Heart rate	Hematocrit	Cardiac
Cardiac rhythm	Sodium	Gastrointestinal
Systolic blood pressure	Potassium	Nutrition/dietary
Diastolic blood pressure	Chloride	Genitourinary
Pulse oximetry	Blood urea nitrogen	Musculoskeletal
Respiratory rate	Creatinine	Neurologic
		Peripheral vascular
		Braden score
		Skin
		Psychosocial
		Safety

The Rothman Index is currently used at 70 hospitals to plot patient condition with time and to assess risk for adverse events. Although it was developed as a more general evaluation of patient condition, rather than to predict a specific complication, it has been shown in certain populations to be helpful in predicting 24-hour mortality [11], sepsis [25], intensive care unit (ICU) mortality [26], ICU readmission [24], discharge to a higher level of care [26], and 30-day readmissions [5]. However, despite its utility and widespread access, the Rothman Index remains underused for many conditions and for physician decision-making. Furthermore, to the best of our knowledge, there are no published studies specifically investigating the association of the Rothman Index with adverse events for patients aged ≥ 65 years with hip fractures.

Therefore, we asked: (1) Is there an association between Rothman Index scores and postdischarge adverse events in a population aged 65 years and older with hip fractures? (2) What is the discriminative ability of Rothman Index scores in determining which patients will or will not experience these adverse events? (3) Are there Rothman Index thresholds associated with increased incidence of post-discharge adverse outcomes?

Patients and Methods

A retrospective review of prospectively collected data was conducted at a large academic medical center. Patients who experienced a hip fracture in the years 2013 to 2016 were identified at the institution and confirmed based on International Classification of Diseases, 9th Revision (ICD-9) or 10th Revision (ICD-10) codes for hip fracture (820.X in ICD-9; S72.X or M80.X in ICD-10). Patients who underwent surgery were further identified by the following Current Procedural Terminology codes: 27236 (repair of femoral neck fracture using internal fixation or prosthetic replacement), 27244 (repair of intertrochanteric fracture using plate/screw fixation), 27245 (repair of trochanteric fracture using intramedullary implant), 27125 (hemi-arthroplasty), or 27130 (THA).

Because the mechanism of injury and expected outcome of hip fracture in elderly or geriatric patients is different from those of younger patients [13, 20], patients were excluded for age younger than 65 years [18, 28, 33]. Additionally, because the study focused on postdischarge events, patients who died in the hospital were excluded from the analysis.

Rothman Index values for the study population were obtained from the electronic medical record from the patients' hospital stays. The Rothman Index is owned by PeraHealth (Charlotte, NC, USA) and is sold to hospitals and health systems. To our knowledge, physicians and researchers must be affiliated with an institution that uses the Rothman Index to access its data. The variable definitions and process to create the Rothman Index are published and available to the public [26]; the algorithm is proprietary and not accessible, even to those at affiliated institutions. Age, sex, body mass index (BMI), and American Society of Anesthesiologists (ASA) class also were obtained for each patient. Surgical procedure performed was characterized as plate/fixation, intramedullary implant, hemiarthroplasty, or THA.

Various adverse events occurring after discharge, within 30 postoperative days, were available for each patient from the institution's American College of Surgeons National Surgical Quality Improvement Program® (ACS-NSQIP®) database. The ACS-NSQIP data set was selected because patients are prospectively identified, reviews are performed by trained clinical reviewers, there are clear definitions for all variables, and patients are followed to postoperative Day 30 regardless of the timing of hospital discharge, enabling out-of-hospital events to be recorded. However, ACS-NSQIP lacks data on reasons for readmission, outpatient followup and support, or clinician rationale in deciding whether a patient should be readmitted, which limit its utility in studying readmission. Among these variables, the following events were considered major adverse events: deep or organ space surgical site infection, prolonged mechanical ventilation > 48 hours, unplanned reintubation, acute renal failure, sepsis or septic shock, venous thromboembolism (deep vein thrombosis or pulmonary embolism), stroke, cardiac arrest, myocardial infarction, return to the operating room, and death. The following were considered minor adverse events: superficial surgical site infection, wound dehiscence, pneumonia, urinary tract infection, and renal insufficiency. The occurrence of a major or minor adverse event or readmission within 30 postoperative days was regarded as "any adverse event." All variables were defined according to ACS-NSQIP guidelines [2].

Preliminary analysis indicated that lowest and latest Rothman Index values were most closely tied to the occurrence of adverse events after discharge, so these were the focus of the analysis. Because of the retrospective analysis of the data, it was not possible to accurately study individual scores, because patients may have many scores generated per day and associate the specific timing of the scores with specific adverse events. Instead, certain key value (earliest, lowest, highest, mean, and latest) scores were tested, and lowest and latest scores were further studied.

To study whether there was a significant association between Rothman Index scores and postdischarge adverse events, multivariate logistic regression was performed to determine the effect of lowest and latest Rothman Index values on the occurrence of any adverse event, major adverse event, mortality, and readmission. Each analysis controlled for patient age, sex, BMI, ASA Class IV versus ASA Classes I through III, and surgical procedure performed. ASA class was selected in favor of more detailed measures such as the Charlson Comorbidity Index, because prior research has demonstrated ASA class to be equal or superior to these calculated measures in the ACS-NSQIP database [22]. With equivalent or better performance, combined with its simplicity and lower rates of missing data, ASA class was chosen as the measure of medical comorbidity [30].

Next, to study the discriminative ability of the Rothman Index to identify which patients will experience adverse events, the lowest and latest Rothman Index values were evaluated by area under the curve (AUC) analysis of a receiver operating characteristic (ROC) curve. A ROC curve is a graphic characterization of a test's performance, where the test's true-positive rate (sensitivity, y-axis) and false-positive rate (1 – specificity, x-axis) are compared at various thresholds [21]. This graphic representation can be further described by the AUC, also known as c-statistic, which can range from 0 to 1 with 0.5 equivalent to random chance and 1 indicating perfect predictive ability [15, 29]. The AUC for the lowest and latest Rothman Index values was determined for the outcomes of any adverse event, major adverse event, mortality, and readmission within 30 postoperative days. The AUC values for lowest and latest Rothman Indices then were compared with the AUC for age, male sex, and ASA class using the DeLong method [9].

Table 2. Demographics

Variable	Mean ± SD or percentage*
Total number of patients	1214
Age (years)	85 ± 8
Female sex	73% (885)
BMI (kg/m^2)	24 ± 5
ASA class	
I-II	21% (260)
III	63% (765)
IV	16% (189)
Surgical procedure	
Plate/screw fixation	20% (248)
Intramedullary implant	35% (422)
Hemiarthroplasty	42% (507)
THA	3% (37)
Length of stay (days)	5.7 ± 3.9

*For percentages, the number in parentheses indicates the total number of patients in a given category.
BMI = Body Mass Index; ASA = American Society of Anesthesiologists.

Finally, to determine whether there are Rothman Index thresholds associated with increased incidence of postdischarge adverse events, the incidence of any adverse event, major adverse event, and mortality was calculated based on 10-unit groupings of patients' lowest and latest Rothman Index values. A locally weighted scatterplot smoothing trend line was created to further characterize the incidence. The Rothman Index value (rounded to the nearest five) at which the incidence of each postdischarge outcome was significantly greater than the overall incidence in the cohort was assessed for each event based on where the trend line was greater than the upper 95% confidence interval (CI) of the overall incidence.

All statistical tests were performed using Stata® version 13.1 (StataCorp LP, College Station, TX, USA). All tests were two-tailed with level of significance set at $p < 0.05$. Approval from the Human Investigations Committee at the authors' institution was obtained before starting the study.

There were 1214 patients aged ≥ 65 years identified with hip fractures. After excluding inpatient mortalities, 1185 patients were included in the study. Mean (± SD) age was 85 ± 8 years. The sample was 73% female. Mean BMI was 24 ± 5 kg/m^2. Mean hospital length of stay was 5.7 ± 3.9 days (Table 2). There were no differences in the demographics of patients who died in the hospital versus those who did not. Of the study population, in-hospital adverse events were noted for 11%, and postdischarge events were noted for 20% (Table 3). The most common postdischarge adverse events were readmission (14%), death (5%), return to the operating room (3%), and pneumonia (3%). The lowest Rothman Index values ranged from -28.5 to 77.0 with a mean of 43.3 ± 17.4 (Fig. 1). The latest Rothman Index values ranged from -0.9 to 95.0 with a mean of 65.3 ± 14.6 (Fig. 2).

Results

The Rothman Index had a strong association with any adverse event, major adverse event, mortality, and readmission after controlling for demographics, comorbidity, and surgical procedure. A 10-unit decline in lowest Rothman Index value was associated with experiencing any adverse event (odds ratio [OR], 1.29; 95% CI, 1.18-1.41; $p < 0.001$), major adverse event (OR, 1.41; 95% CI, 1.26-1.57; $p < 0.001$), mortality (OR, 1.77; 95% CI, 1.50-2.09; $p < 0.001$), and readmission (OR, 1.19; 95% CI, 1.08-1.31; $p < 0.001$) (Table 4). Similarly, a 10-unit decline in the latest Rothman Index value was associated with experiencing any adverse event (OR, 1.37; 95% CI, 1.24-1.52; $p < 0.001$), major adverse event (OR, 1.53; 95% CI, 1.35-1.74; $p < 0.001$), mortality (OR, 2.28; 95% CI, 1.87-2.79; p <

Table 3. Incidence of adverse events

Adverse event	In-hospital events*		Postdischarge events†	
	Number of patients	Percentage of patients	Number of patients	Percentage of patients
Any	135	11	232	20
Major	90	7	127	11
Deep surgical site infection	2	0	10	1
Mechanical ventilation > 48 hours	12	1	3	0
Unplanned reintubation	26	2	15	1
Acute renal failure	5	0	1	0
Sepsis/septic shock	16	1	26	2
Venous thromboembolism	24	2	21	2
Stroke	3	0	2	0
Cardiac arrest	13	1	2	0
Myocardial infarction	18	1	7	1
Return to operating room	8	1	35	3
Death	29	2	56	5
Minor	71	6	62	5
Superficial surgical site infection	0	0	11	1
Wound dehiscence	0	0	0	0
Pneumonia	53	4	31	3
Urinary tract infection	16	1	23	2
Renal insufficiency	3	0	1	0
Readmission	N/A	N/A	171	14

*For in-hospital events, percentages are of n = 1214.
†for postdischarge events, patients who died in the hospital were excluded and percentages were calculated from n = 1185; N/A = not available.

0.001), and readmission (OR, 1.15; 95% CI, 1.03-1.29; p = 0.014) (Table 4).

The discriminative ability of lowest and latest Rothman Index scores was better than those of age, sex, and ASA class for any adverse event, major adverse event, and mortality after discharge. However, the lowest and latest Rothman Index scores were only superior to age for readmission, whereas there was no difference compared with sex and ASA class. For any adverse event, lowest Rothman Index value (AUC = 0.641; 95% CI, 0.601-0.681) and latest Rothman Index value (0.640; 95% CI, 0.600-0.680) were superior to age (0.534; 95% CI, 0.493-0.575; p < 0.001 for both), male sex (0.552; 95% CI, 0.518-0.585; p = 0.001 for both), and ASA class (0.578; 95% CI, 0.542-0.614; p = 0.004 for lowest Rothman Index, p = 0.006 for latest Rothman Index). For major adverse event, the lowest (0.682; 95% CI, 0.631-0.732) and latest Rothman Index values (0.671; 95% CI, 0.619-0.723) were superior to age (0.520; 95% CI, 0.466-0.573; p < 0.001 for both), male sex (0.576; 95% CI, 0.531-0.620; p = 0.001 for lowest, p = 0.005 for latest), and ASA class (0.579; 95% CI, 0.533-0.625; p < 0.001 for lowest, p = 0.001 for latest). For mortality, the lowest (0.808; 95% CI, 0.753-0.862) and latest Rothman Index values (0.827; 95% CI, 0.765-0.888) were superior to age (0.622; 95% CI, 0.547-0.698; p <

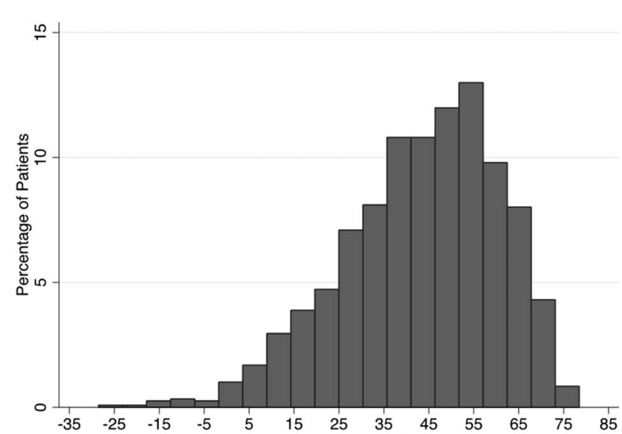

Fig. 1 The distribution of the lowest Rothman Index scores from the patient cohort at the time of their hospital discharges is shown.

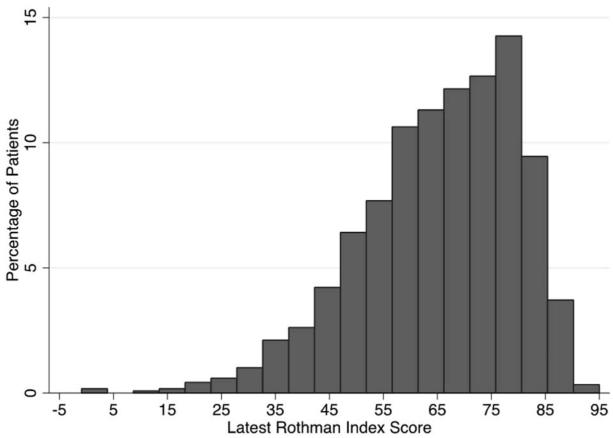

Fig. 2 The distribution of latest Rothman Index scores from the patient cohort at the time of their hospital discharges is shown.

0.001 for both), male sex (0.585; 95% CI, 0.519-0.652; p < 0.001 for both), and ASA class (0.648; 95% CI, 0.584-0.712; p < 0.001 for both). For readmission, lowest (0.598; 95% CI, 0.552-0.644) and latest Rothman Index scores (0.585; 95% CI, 0.540-0.629) were superior to the AUC for age (0.505; 95% CI, 0.460-0.551; p = 0.003 for lowest, p = 0.007 for latest) but were not different from male sex (0.543; 95% CI, 0.505-0.581; p = 0.073 for lowest, p = 0.167 for latest) or ASA class (0.550; 95% CI, 0.509-0.590; p = 0.074 for lowest, p = 0.207). There was never a difference when comparing lowest Rothman Index value and latest Rothman Index value for any of the outcomes.

As the lowest Rothman Index scores increased, there was a steady decline in the incidence of any adverse event (Fig. 3A), major adverse event (Fig. 3B), and mortality (Fig. 3C). Similarly, as the latest Rothman Index scores increased, there was an associated decreasing incidence of any adverse event (Fig. 4A), major adverse event (Fig. 4B), and mortality (Fig. 4C). In the study sample, the overall incidence of any adverse event in the population was 19.6% (95% CI, 17.4%-22.0) (Figs. 1B, 2B), whereas the incidence of major adverse events was 10.7% (95% CI, 9.0%-12.6%) (Figs. 1C, 2C). The mortality rate was 4.7% (95% CI, 3.6%-6.1) (Figs. 1D, 2D). Based on the incidence and sample size, binomial exact CIs were calculated, and the upper bound of the 95% CI was plotted on the figures. Compared with the overall cohort, patients experienced increased incidence of all three outcomes when the lowest Rothman Index score was < 35 and when the latest Rothman Index score was < 55 (Figs. 3A-C, 4A-C, arrows).

Discussion

As the healthcare system increasingly emphasizes value of care and seeks to reduce drivers of morbidity and cost, there is great utility in tools that facilitate clinicians and health systems to better anticipate which patients are vulnerable to complications. Geriatric patients with hip fractures, with high rates of postoperative complications and mortality, could potentially experience improved perioperative outcomes if there is a reliable method to identify those who might be at greater risk of adverse events. Whereas much of the orthopaedic literature has investigated preoperative demographics and comorbidities for potential associations [1, 3, 12, 14, 16,

Table 4. Multivariate regression for association with adverse events

Independent variable	Any adverse event		Major adverse event		Mortality		Readmission	
	OR (95% CI)	p value	OR (95% CI)	p value	OR (95% CI)	p value	OR (95% CI)	p value
Lowest Rothman Index value	1.29 (1.18-1.41)*	< 0.001	1.41 (1.26-1.57)*	< 0.001	1.75 (1.48-2.07)*	< 0.001	1.19 (1.08-1.31)*	< 0.001
Age	1.01 (0.99-1.03)	0.271	1.00 (0.98-1.03)	0.845	1.05 (1.01-1.09)*	0.021	1.00 (0.98-1.02)	0.878
Male sex	1.53 (1.11-2.13)*	0.010	1.82 (1.21-2.74)*	0.004	2.02 (1.09-3.75)*	0.025	1.38 (0.96-1.99)	0.082
BMI	1.01 (0.98-1.04)	0.701	0.98 (0.94-1.02)	0.349	0.97 (0.91-1.03)	0.324	1.02 (0.98-1.05)	0.319
ASA Class IV or higher	1.37 (0.93-2.01)	0.110	1.21 (0.75-1.95)	0.432	1.41 (0.74-2.67)	0.298	1.22 (0.79-1.89)	0.374
Latest Rothman Index value	1.37 (1.24-1.52)*	< 0.001	1.54 (1.35-1.75)*	< 0.001	2.28 (1.86-2.78)*	< 0.001	1.15 (1.03-1.29)*	0.014
Age	1.02 (0.99-1.03)	0.491	1.00 (0.97-1.02)	0.770	1.04 (0.99-1.08)	0.091	1.00 (0.98-1.02)	0.872
Male sex	1.56 (1.13-2.17)*	0.008	1.88 (1.25-2.83)*	0.002	2.40 (1.26-4.53)*	0.007	1.42 (0.99-2.04)	0.056
BMI	1.01 (0.98-1.04)	0.678	0.98 (0.94-1.02)	0.418	0.97 (0.91-1.04)	0.430	1.02 (0.98-1.05)	0.323
ASA Class IV or higher	1.41 (0.96-2.07)	0.077	1.26 (0.78-2.02)	0.340	1.40 (0.73-2.68)	0.316	1.34 (0.87-2.06)	0.184

*Significance at p < 0.05; for lowest and latest Rothman Index values, the odds ratio (OR) represents a 10-unit decrease in Rothman Index value; regression analysis also controlled for surgical procedure; however, procedure type was never statistically significant and was not included in the table; CI = Confidence Interval; BMI = Body Mass Index; ASA = American Society of Anesthesiologists.

Table 5. Receiver operating characteristic curve analysis of postdischarge adverse events

Independent variable	Any adverse event AUC (95% CI)	p value	Major event AUC (95% CI)	p value	Mortality AUC (95% CI)	p value	Readmission AUC (95% CI)	p value
Lowest Rothman Index value	0.641 (0.601-0.681)	N/A	0.682 (0.631-0.732)	N/A	0.808 (0.753-0.862)	N/A	0.598 (0.552-0.644)	N/A
Age	0.534 (0.493-0.575)*	0.000	0.520 (0.466-0.573)*	0.000	0.622 (0.547-0.698)*	0.000	0.505 (0.460-0.551)*	0.003
Male sex	0.552 (0.518-0.585)*	0.001	0.576 (0.531-0.620)*	0.001	0.585 (0.519-0.652)*	0.000	0.543 (0.505-0.581)	0.073
ASA class	0.578 (0.542-0.614)*	0.004	0.579 (0.533-0.625)*	0.000	0.648 (0.584-0.712)*	0.000	0.550 (0.509-0.590)	0.074
Independent variable	**Any adverse event AUC (95% CI)**	**p value**	**Major event AUC (95% CI)**	**p value**	**Mortality AUC (95% CI)**	**p value**	**Readmission AUC (95% CI)**	**p value**
Latest Rothman Index value	0.640 (0.600-0.680)	N/A	0.671 (0.619-0.723)	N/A	0.827 (0.765-0.888)	N/A	0.585 (0.540-0.629)	N/A
Age	0.534 (0.493-0.575)†	0.000	0.520 (0.466-0.573)†	0.000	0.622 (0.547-0.698)†	0.000	0.505 (0.460-0.551)†	0.007
Male sex	0.552 (0.518-0.585)†	0.001	0.576 (0.531-0.620)†	0.005	0.585 (0.519-0.652)†	0.000	0.543 (0.505-0.581)	0.167
ASA class	0.578 (0.542-0.614)†	0.006	0.579 (0.533-0.625)†	0.001	0.648 (0.584-0.712)†	0.000	0.550 (0.509-0.590)	0.207

*The area under the curve (AUC) is significantly different from that of the lowest Rothman Index value ($p < 0.05$)
†the AUC is significantly different from that of the latest Rothman Index value ($p < 0.05$); there were no significant differences between the AUC for lowest Rothman Index value and latest Rothman Index value for any of the outcomes; in the upper portion of the table, p values are calculated for comparing the AUC with that of the lowest Rothman Index value; in the lower portion of the table, p values are calculated for comparing the AUC with that of the latest Rothman Index value; CI = confidence interval; ASA = American Society of Anesthesiologists; N/A = not available.

17, 19, 27], the current study investigated the Rothman Index, a composite score calculated from data in the electronic medical record and updated throughout the hospitalization. It was found that lowest and latest Rothman Index scores were independently associated with the incidence of postdischarge adverse events, readmission, and mortality after hip fracture surgery.

The current study has several limitations. Notably, only postdischarge events were considered in investigating the Rothman Index. Because this index is only available in the inpatient setting, this guarantees that all Rothman Index scores preceded the complications that were studied. This temporal relationship suggests that this index can be used to anticipate complications rather than simply decline in response to them. However, its association with inpatient complications was not studied and is a potential subject for future investigation. In studying readmission as an outcome measure, the study may have been limited by the complexity of studying hospital readmissions. Whether a patient is readmitted depends on the presenting complaint, access to outpatient care, psychosocial factors, and patient and physician preference. Although a strength of utilizing NSQIP data was the ability to capture readmissions at other facilities, it was not possible to characterize reasons for readmission or to understand. These complex factors may contribute to the Rothman Index's relatively poor performance with readmission. Although the Rothman Index was designed to make its input quantifiable and objective, some of the nursing assessment variables still require human judgment. For example, the psychosocial component includes "behavior appropriate to situation," whereas the nutritional component includes "patient consuming > 50% of daily diet as observed" [26]. As such, there is potential for interrater discrepancies that may diminish the accuracy or precision of the Rothman Index. Another limitation is that because the Rothman Index is a proprietary algorithm, it is not possible to know the relative weights of the variables and use that information to craft interventions on patient care. Additionally, patients were followed only until postoperative Day 30, consistent with NSQIP collection practices [2]. Patients with hip fractures might experience complications beyond this 30-day period [6]; therefore, the current study does not completely characterize their entire course. Furthermore, the current study did not address the benefits and costs of making clinical decisions (eg, deciding whether to discharge a patient) based on Rothman Index scores.

We found that declining lowest and latest Rothman Index scores were associated with increasing rates of postdischarge adverse events, mortality, and readmission in the geriatric population with hip fractures, even after controlling for demographic variables and baseline level of

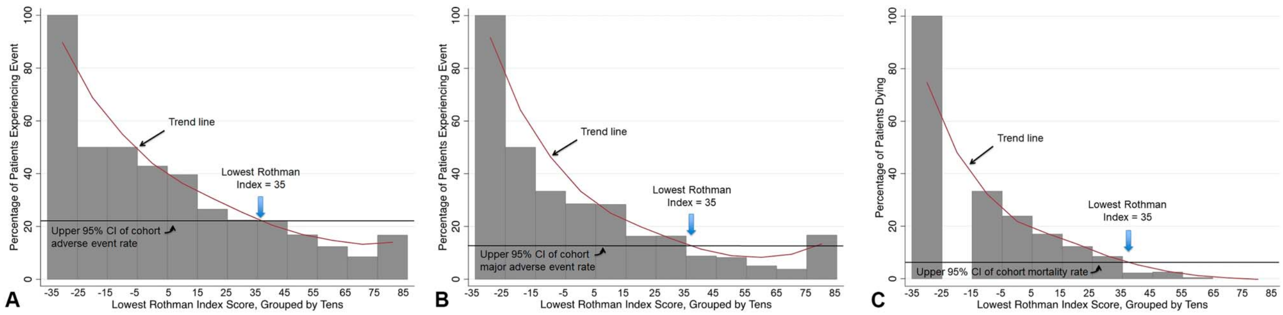

Fig. 3 A-C (**A**) The incidence of any postdischarge adverse event by lowest Rothman Index score with locally weighted scatterplot smoothing trend line is shown. The horizontal line indicates upper 95% CI of cohort any adverse event rate (22.0%). The arrow signifies the point where the trend line intersects the upper 95% CI such that lower Rothman Index values are experiencing a significantly greater rate of any adverse event; this corresponds to a Rothman Index of 35 based on the rounding to the nearest five described in the text. (**B**) The incidence of postdischarge major adverse event by lowest Rothman Index score is shown with a locally weighted scatterplot smoothing trend line. The horizontal line indicates upper 95% CI of cohort readmission rate (12.6%). The arrow signifies the point where the trend line intersects the upper 95% CI such that lower Rothman Index values are experiencing a significantly greater readmission rate; this corresponds to a Rothman Index of 35 based on the rounding to the nearest five described in the text. (**C**) The mortality rate by lowest Rothman Index score is shown with a locally weighted scatterplot smoothing trend line. The horizontal line indicates upper 95% CI of cohort readmission rate (6.1%). The arrow signifies the point where the trend line intersects upper 95% CI such that lower Rothman Index values are experiencing a significantly greater readmission rate; this corresponds to a Rothman Index of 35 based on the rounding to the nearest five described in the text.

comorbidity. This has been observed in other disciplines. For example, Tepas et al. [31] found that declining Rothman Index scores were associated with adverse events, greater length of stay, and higher hospital costs in a general medical and surgical inpatient population. In a similar population, Bradley et al. [5] reported that a 20-unit difference in Rothman Index at discharge was associated with a 2.4-fold increase in odds of readmission within 30 days. However, prior studies have included all patients and diagnoses either in an entire hospital or in an intensive care setting. To our knowledge, our study is the first to investigate the Rothman Index in a population with one particular diagnosis.

We found that the Rothman Index exhibits strong performance with mortality and moderate performance with major adverse events [29]. Discriminative ability was found to be

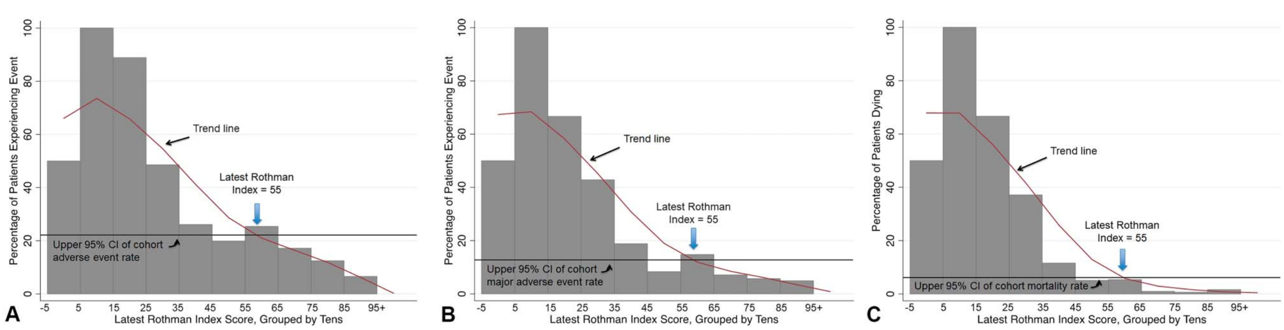

Fig. 4 A-C (**A**) The incidence of postdischarge any adverse event by latest Rothman Index score is shown with a locally weighted scatterplot smoothing trend line. The horizontal line indicates upper 95% CI of cohort any adverse event rate (22.0%). The arrow signifies the point where the trend line intersects upper 95% CI such that lower Rothman Index values are experiencing a significantly greater rate of any adverse event; this corresponds to a Rothman Index of 55 based on the rounding to the nearest five described in the text. (**B**) The incidence of postdischarge major adverse event by latest Rothman Index score is shown with locally weighted scatterplot smoothing trend line. The horizontal line indicates upper 95% CI of the cohort readmission rate (12.6%). The arrow signifies the point where the trend line intersects upper 95% CI such that lower Rothman Index values are experiencing a significantly greater readmission rate; this corresponds to a Rothman Index of 55 based on the rounding to the nearest five described in the text. (**C**) The mortality rate by latest Rothman Index score is shown with a locally weighted scatterplot smoothing trend line. The horizontal line indicates upper 95% CI of cohort readmission rate (6.1%). The arrow signifies the point where the trend line intersects upper 95% CI such that lower Rothman Index values are experiencing a significantly greater readmission rate; this corresponds to a Rothman Index of 55 based on the rounding to the nearest five described in the text.

poorest with readmission, where its performance was better only than that of age. Whereas such analysis of discriminative ability has been limited in prior studies, Rothman and colleagues performed a similar analysis in their original publication on the Rothman Index. In a general hospital population, the Rothman Index's performance with 30-day readmission was notably poorer than that of 24-hour mortality or nonhome discharge, and the reported AUC of 0.62 was comparable to those in the current study [26]. The contributions of psychosocial factors—such as home environment and availability of caregivers—and variations in patient preference and physician decision-making, as noted previously, may contribute to the poorer performance of the Rothman Index with readmission, and further investigation how physicians can anticipate readmissions or stratify patient risk after hip fracture is needed.

Additionally, within the study sample, patients with a lowest Rothman Index score of ≤ 35 or latest Rothman Index score of ≤ 55 experienced a greater incidence of adverse events and mortality than that of the overall patient population. These values may be used by physicians and other caregivers to stratify patient risk for adverse events as well as to counsel patients and families about possible increased risk of complications after hip fracture. Of note, the values obtained were consistent with the Rothman Index values that maximized the AUC, which occurred at values of 34 to 44 for lowest and 51 to 67 for latest Rothman Index scores. In previous studies, Bradley and colleagues suggested Rothman Index scores < 70 are associated with increased risk of readmission in a general hospital population [5], whereas Piper and colleagues suggested a score of ≥ 83 as indicating that patients in a surgical ICU may be safely transferred to the floor [24]. For general applications, Rothman et al. suggested that index scores of ≥ 65 are "low risk," 40 to 64.9 are "intermediate risk," and scores < 40 are high risk [26], and these values were reasonably close to those in the current study. It is likely that Rothman Index thresholds vary with the patient population and primary diagnosis or treatment, and future investigations could determine the degree of variability in risk among different conditions. Additionally, future studies are needed to validate the thresholds identified here in separate populations of patients with hip fracture.

The Rothman Index is a comprehensive measure of patient condition associated with postdischarge adverse events, mortality, and readmission after hip fracture surgery in patients aged ≥ 65 years. Physicians may use the Rothman Index to monitor their patients' condition in real time and to discern which patients face an increased risk of adverse events. Additionally, it can be used as a tool to educate patients and families about their current condition and their level of risk for experiencing adverse events after discharge. Prospective, interventional studies are needed to determine whether changing patient care (eg, extending length of stay, discharging patient to a higher level of care) based on Rothman Index scores leads to improvements in the quality or value of care for patients with hip fracture.

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