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

Ryan P. McLynn BS, Taylor D. Ottesen BS, Nathaniel T. Ondeck BS, Jonathan J. Cui BS, Lee E. Rubin MD, Jonathan N. Grauer MD

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 postdischarge adverse outcomes were calculated. The associations between a 10-unit change in Rothman Index scores and postdischarge adverse outcomes were calculated.
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 \( \leq 35 \) (\( p < 0.05 \)) or latest Rothman Index of \( \leq 55 \) (\( p < 0.05 \)).

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 \( \geq 65 \) years will increase 80% by 2050 [8], whereas the population \( \geq 85 \) 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 (PeriHealth, 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                  |
| Systolic blood       | Sodium                | Gastrointestinal         |
| pressure             | Potassium             | Nutrition/dietary        |
| Diastolic blood      | Chloride              | Genitourinary            |
| Pressure             |                       |                          |
| 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 postdischarge 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 (hemiarthroplasty), 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/m²)                     | 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/m². 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 <
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 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 <

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.

Fig. 1 The distribution of the lowest 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) * | 0.000 | 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 |

| 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.
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. 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.

Fig. 4 A-C (A) The incidence of postdischarge any 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 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 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 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.
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 complications after hip fracture. Of note, 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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References
1. Ali AM, Gibbons CE. Predictors of 30-day hospital readmission after hip fracture: a systematic review. *Injury*. 2017;48:243–252.
2. American College of Surgeons. User Guide for the 2015 ACS NSQIP Participant Use Data File. Chicago, IL, USA: American College of Surgeons; 2016. Available at: https://www.facs.org/~media/files/qualityprograms/nsqip/nsqip_puf_user_guide_2015.aspx. Accessed October 26, 2017.
3. Basques BA, Bohd DL, Golivaux NS, Leslie MP, Baumgarter MR, Grauer JN. Postoperative length of stay and 30-day readmission after geriatric hip fracture: an analysis of 8434 patients. *J Orthop Trauma*. 2015;29:e115–120.
4. Bentler SE, Lui L, Obrizan M, Cook EA, Wright KB, Geweke JF, Chrischilles EA, Pavlik CE, Wallace RB, Ohsfeldt RL, Jones MP, Rosenthal GE, Wolinsky FD. The aftermath of hip fracture: Discharge placement, functional status change, and mortality. *Am J Epidemiol*. 2009;170:1290–1299.
5. Bradley EH, Yakusheva O, Horwitz LI, Sigsma H, Fletcher J. Identifying patients at increased risk for unplanned readmission. *Med Care*. 2013;51:761–766.
6. Brauer CA Coca-Perraillon M, Cutler DM, Rosen AB. Incidence and mortality of hip fractures in the United States. *JAMA*. 2009;302:1573–1579.
7. Burge R, Dawson-Hughes B, Solomon DH, Wong JB, King A, Tosteson A. Incidence and economic burden of osteoporosis-related fractures in the United States, 2005-2025. *J Bone Miner Res*. 2007;22:465–475.
8. Colby SL, Ortmann JM. Projections of the size and composition of the US population: 2014 to 2060. Current Population Reports, March 2015. Available at: https://www.census.gov/content/dam/Census/library/publications/2015/demo/p25-1143.pdf. Accessed October 20, 2017.
9. DeLong ER, DeLong DM, Clarke-Peterson DL. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. *Biometrics*. 1988;44:837–845.
10. Dy CJ, McCollister KE, Lubarsky DA, Lane JM. An economic evaluation of a systems-based strategy to expedite surgical treatment of hip fractures. *J Bone Joint Surg Am*. 2011;93:1326–1334.
11. Finlay GD, Rothman MJ, Smith RA. Measuring the modified early warning score and the Rothman Index: advantages of utilizing the electronic medical record in an early warning system. *J Hosp Med*. 2014;9:116–119.
12. Giusti A, Barone A, Razzano M, Pizzonia M, Oliveri M, Pioli G. Predictors of hospital readmission in a cohort of 236 elderly discharged after surgical repair of hip fracture: one-year follow-up. *Aging Clin Exp Res*. 2008;20:253–259.
13. Haidukeywych GJ, Rothwell WS, Jacofsky DJ, Torchia ME, Berry DJ. Operative treatment of femoral neck fractures in patients between the ages of fifteen and fifty years. *J Bone Joint Surg Am*. 2004;86:1711–1716.
14. Halm EA, Wang JJ, Boockvar K, Penrod J, Silberzweig SB, Magaziner J, Koval KJ, Siu AL. The effect of perioperative...
anemia on clinical and functional outcomes in patients with hip fracture. *J Orthop Trauma.* 2004;18:369–374.
15. Hanley JA, McNeil BJ. The meaning and use of the area under a receiver operating characteristic (ROC) curve. *Radiology.* 1982;143:29–36.
16. Härstedt M, Rogmark C, Sutton R, Melander O, Fedorowski A. Impact of comorbidity on 6-month hospital readmission and mortality after hip fracture surgery. *Injury.* 2015;46:713–718.
17. Heyes GJ, Tucker A, Marley D, Foster A. Predictors for readmission up to 1 year following hip fracture. *Arch Trauma Res.* 2015;4:e27123.
18. Ikpeze TC, Mohney S, Elfar JC. Initial preoperative management of geriatric hip fractures. *Geriatr Orthop Surg Rehabil.* 2017;8:64–66.
19. Khan MA, Hossain FS, Dashti Z, Muthukumar N. Causes and predictors of early readmission after surgery for fracture of the hip. *J Bone Joint Surg Br.* 2012;94:690–697.
20. Ly TV, SWATtonkowski MF. Management of femoral neck fractures in young adults. *Indian J Orthop.* 2008;42:3–12.
21. Nettleman MD. Receiver operator characteristic (ROC) curves. *Infect Control Hosp Epidemiol.* 1988;9:374–377.
22. Ondeck NT, Bohl DD, Bovonratwet P, McLynn RP, Cui JJ, Shultz BN, Lukasiewicz AM, Grauer JN. Discriminative ability of common comorbidity indices to predict adverse outcomes after posterior lumbar fusion: a comparison of demographics, ASA, the modified Charlson Comorbidity Index, and the modified Frailty Index. *Spine J.* 2017 May 31. [Epub ahead of print]
23. Ortman JS, Velkoff VA, Hogan H. An aging nation: the older population in the United States. Population estimates and projections. Current Population Reports, May 2014. Available at: [https://www.census.gov/prod/cen2014pubs/p25-1140.pdf](https://www.census.gov/prod/cen2014pubs/p25-1140.pdf). Accessed October 20, 2017.
24. Piper GL, Kaplan LJ, Maung AA, Lui FY, Barre K, Davis KA. Using the Rothman Index to predict early unplanned surgical intensive care unit readmissions. *J Trauma Acute Care Surg.* 2014;77:78–82.
25. Rothman M, Levy M, Dellingler RP, Jones SL, Fogerty RL, Voelker KG, Gross B, Marchetti A, Beals J 4th. Sepsis as 2 problems: identifying sepsis at admission and predicting onset in the hospital using an electronic medical record-based acuity score. *J Crit Care.* 2016;38:237–244.
26. Rothman MJ, Rothman SI, Beals J 4th. Development and validation of a continuous measure of patient condition using the electronic medical record. *J Biomed Inform.* 2013;46:837–848.
27. Sathiyakumar V, Greenberg SE, Molina CS, Thakore RV, Obrensky WT, Sethi MK. Hip fractures are risky business: an analysis of the NSQIP data. *Injury.* 2015;46:703–708.
28. Scheffers-Barnhoorn MN, van Haastregt JC, Schols JMGA, Kempen GIJM, van Balen R, Visschedijk JHM, van den Hout WB, Dumas EM, Achterberg WP, van Eijk M. A multi-component cognitive behavioral intervention for the treatment of fear of falling after hip fracture (FIT-HIP): protocol of a randomized controlled trial. *BMC Geriatr.* 2017;17:71.
29. Schneeweiss S, Wang PS, Avorn J, Glynn RJ. Improved comorbidity adjustment for predicting mortality in Medicare populations. *Health Serv Res.* 2003;38:1103–1120.
30. Shultz BN, Ottesen TD, Ondeck NT, Bovonratwet P, McLynn RP, Cui JJ, Grauer JN. Systematic Changes in the National Surgical Quality Improvement Program database over the years can affect comorbidity indices such as the Modified Frailty Index and Modified Charlson Comorbidity Index for lumbar fusion studies. *Spine (Phila Pa 1976).* 2017 Sep 15. [Epub ahead of print]
31. Tepas JJ 3rd, Rimar JM, Hsiao AL, Nussbaum MS. Automated analysis of electronic medical record data reflects the pathophysiology of operative complications. *Surgery.* 2013;154:918–924.
32. Wolinsky FD, Fitzgerald JF, Stump TE. The effect of hip fracture on mortality, hospitalization, and functional status: a prospective study. *Am J Public Health.* 1997;87:398–403.
33. Zywiel MG, Hurley RT, Perruccio AV, Hancock-Howard RL, Coyte PC, Ramsersaud YR. Health economic implications of perioperative delirium in older patients after surgery for a fragility hip fracture. *J Bone Joint Surg Am.* 2015;97:829–836.