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A simple clinical risk nomogram to predict mortality-associated geriatric complications in severely-injured geriatric patients

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Background

As they enter their retirement years, a generation of 76 million baby boomers with chronic illnesses and a goal to remain independent will increase the need for efficient and effective trauma care.¹⁻³ Geriatric trauma patients have less resilience to their injuries than younger patients with comparably severe injury,⁴⁻⁸ including poorer survival and greater complication rates.^{5,9,10} Although hospital survival has long been viewed as the most important hospital outcome, medical complications of surgery and traumatic injury have become an important comparative measure of hospital and surgical quality of care.¹¹

Some post-injury complications such as pneumonia and coagulopathy are more prevalent with age⁹ and might represent a target for future preventive efforts. As prevalence is not necessarily associated with poor outcomes, we took an alternative approach by first prioritizing complications based on differential mortality risk between old versus young patients. We hypothesized that older patients with infectious complications would be more likely to die than younger patients with similar complications, injury severity, and co-morbidity and thus could lead to targeted interventions tailored to older patients. Because current guidelines recommend risk stratification at the time of admission for older patients,^{12,13} we aimed to: (1) identify the complications most associated with mortality, and

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(2) develop a simple clinical risk nomogram to predict patients at greatest risk for Mortality-associated Geriatric Complications (MGCs).

Methods

Sample identification (Figure 1)

The National Trauma Data Bank (NTDB 7.0), a voluntary registry of over 500 Level 1, 2, and 3 trauma centers,¹⁴ was used to identify all patients age 18 and older from 2001-2005 with injuries above moderate severity, defined by Injury Severity Score (ISS) >15. The ISS is a continuous variable ranging from 0 to 75 that, reflects the overall severity of injury across a trauma patients' bodily regions, with higher scores representing greater severity.¹⁵ We excluded patients who died within 24 hours of admission, were transferred to another facility, or were dead on arrival. Traumatic incidents identified in the NTDB were assumed to be unique patients.

Preliminary analysis to define Mortality-Associated Geriatric Complications (MGCs)

Predictor variables—These preliminary analyses screened 21 complications collected in the NTDB¹⁴ (Table 1) as predictor variables for mortality. We considered each complication as a dichotomous variable. We used count of co-morbidities (out of 16 possible), ISS, and gender as co-variables in the preliminary analysis.

Primary outcome—Death was collected by the NTDB as part of the hospital discharge status and discharge disposition variables.

Stratifying variable—Age was considered as a stratifying variable for all preliminary analyses, with age 18-64 years considered as young adults and ≥ 65 years as older adults. Because the NTDB does not report the exact age for all patients of age ≥ 90 years, we considered patients with masked old age as equal to 90 years.

Statistical Identification of MGCs—We first used unadjusted t-tests (for continuous variables) and Chi-squared tests (for categorical variables) to compare prevalence of each specific complication for younger and older age groups. The prevalence was calculated using separate denominators for each complication according to patients from facilities reporting nonzero complications, a method described in prior work.¹⁶ Next, we predicted risk of hospital mortality for patient subpopulations with each specific complication using 21 separate logistic regressions. The effect of each complication on mortality was adjusted for gender, ISS, and number of comorbidities. We defined Mortality-associated Geriatric Complications (MGCs) as the complications for which the adjusted mortality risk was 2 or more times greater for older patients compared to younger patients.

All standard errors were adjusted for patient clusters within facility. All analyses were performed with STATA 12 (College Station, TX).

Final analysis to develop clinical risk nomogram

Analysis—To develop the clinical risk nomogram, we used logistic regression to predict development of any MGC or death. We were primarily interested in 3 variables obtainable upon trauma hospital admission (age, gender, and co-morbidity), but also included ISS as a control variable. We defined co-morbidity as a three-category variable: healthy (zero conditions), moderate chronic conditions (1-2 conditions) and multi-morbid (3+ conditions). We considered all interactions between gender, age, and co-morbidity and included interaction terms in the final multivariable model based on statistical ($p < .05$) significance.

To obtain predicted risks of developing an MGC or death, we set ISS at a value of 25 (representing severe overall injury). We then predicted risk across increasing age and co-morbidity categories for men and women. Because facilities varied in reporting complications and co-morbidities, the analytic sample predicting MGCs were limited to facilities reporting at least one MGC and at least 3 different pre-existing conditions (Figure 1). All standard errors were adjusted for patient clusters within facility.

Facility-level sampling weights

One limitation of the NTDB is facility-level variation in reporting practices that could potentially result in reporting fewer complications among older patients. We addressed this potential limitation by adding facility-level sampling weights to all multivariable analyses. We considered four facility-level variables reported in the NTDB:¹⁴ whether or not the institution reported non-elderly patients with isolated hip fractures as trauma, whether or not the institution reported that they considered all isolated hip fractures as traumatic injury, academic teaching versus other type of institution, and American College of Surgeons level-1 trauma center designation. These variables have previously been found to affect reporting of complication rates.^{16,17} Next, we calculated two new facility-level predictors: percent of isolated hip fracture injuries (a calculation recommended by the NTDB)¹⁸, and number of patients in our sample contributed from each facility (to represent patient-care volume). We used our original analytic dataset (Figure 1), clustered at the level of the facility, to screen the six potential weighting variables as independent predictors of reporting on older patients (defined as $p < .05$ in a logistic regression model predicting old versus young age). Of the six, we identified four (academic institution, number of patients, facility reporting of isolated hip fractures in non-elderly, and percent of isolated hip fractures). The inverse of each patient's predicted probability of being reported from his or her facility was used as a sampling weight in all analyses.

Results

Of over 1.8 million trauma center admissions reported in the NTDB, 284,985 injured patients met our inclusion criteria (ISS > 15 , age ≥ 18 , not transferred to another hospital, length of stay ≥ 1 day). The mean age was 46 (range 18-90 years), and 71% were male. The proportion of our sample without a reported age (due to patient age > 90) was $< 2\%$, comparable to the next lower age category (age 85-89, 3.1%). Considering patients with masked age as 90 years, the distribution of age appeared as a normal distribution truncated at age 18 and 90. The average ISS was 24 ± 9.6 (range 15-75). Most (90%) were blunt-type injuries. More than half were due to motor vehicle traffic accidents, and 7% were due to low-level falls. Among facilities reporting at least 1 pre-existing condition, a pre-existing condition was present in 31% of patients.

Outcomes

Overall mortality was 15.1%. At least one complication occurred in 14% of eligible patients. When considering the baseline characteristics by old versus young age strata (Table 1 and 2), the old group was less often male (53% versus 76%; $p < 0.001$), and had more pre-existing conditions (58% versus 28% had at least one condition, $p < .001$). There were more low-level falls in the old. Mean injury severity was slightly less severe in the old (23 versus 25; $p < 0.001$). Compared with younger patients, the older group had greater unadjusted hospital mortality (24% versus 13%; $p < 0.001$) and greater unadjusted risk of developing pressure ulcer, urinary tract infection, deep venous thrombosis, aspiration pneumonia, progression of neurologic damage, renal failure, and cardiac arrest (Table 1).

Older adults had an increased adjusted relative risk of dying ($aRR > 2$) compared to younger adults for seven infectious complications (Table 3): abscess, wound infection, empyema, urinary tract infection, pneumonia, bacteremia, and aspiration pneumonia. Additionally, older compared to younger adults had at least double the risk of mortality for six non-infectious complications: failure of reduction/fixation, pressure ulcer, deep venous thrombosis, pneumothorax, pulmonary embolism, and compartment syndrome. These complications were considered as mortality-associated geriatric complications (MGCs).

Among the older adults, 34% developed an MGC or death, compared to 22% in the young adults (two-tailed t-test, $p < .001$). To predict MGCs, we further limited analysis 164,486 patients treated at facilities that reported complications and at least 3 different pre-existing conditions to the NTDB. Among these, 65% had no pre-existing conditions, 28% had 1-2 conditions, and 6% had 3 or more conditions. This new analytic sample (Figure 1) had a greater mean condition count than the original analytic sample, but the increase was similar in magnitude for older versus younger adults (1.2 versus .4 conditions for old versus young, $p < .001$). The new sample also did not differ from the original with respect to proportion male or distribution of ISS (overall and by age group).

In the final multivariable logistic model (Figure 2) using age, gender, ISS, and pre-existing condition category to predict MGC or death, every 5 years of age multiplied the odds of an MGC by 10% (95% CI 8.7%-10.5%). Three or more pre-existing conditions conferred 56% greater odds (95% CI 36%-78%) and 1-2 conditions conferred 29% greater odds (95% CI 15%-47%) than having no conditions. Male patients had 18% greater odds (95% CI 14%-22%) of an MGC or death than female patients ($p < .001$). There was a positive and significant interaction between age and co-morbidity (odds ratio 1.005, $p < .04$ per year for patients with 3+ pre-existing conditions), so the age-co-morbidity interaction was retained in the final model. The Area under the Receiver Operating Curve (which measures model fit) was 74%, representing good fit for the purpose of targeting clinical services.

Discussion

Older patients hospitalized for traumatic injury have more complex and frequently unfavorable clinical courses than younger patients. In this large national dataset of hospitalized patients with moderate to severe traumatic injury, we found that nearly all infections in the post-injury hospital course, including pneumonia, abscess, wound infection, empyema, urinary tract infection, bacteremia, and aspiration pneumonia, were associated with at least double the risk of death for older versus younger patients. Certain non-infectious complications also were identified as associated with greater mortality among older patients, including failure of reduction/fixation, pressure ulcer, deep venous thrombosis, pneumothorax, pulmonary embolism, and compartment syndrome. Based on these age-related mortality differences, we developed a new outcome, mortality-associated geriatric complications (MGCs). By categorizing the level of pre-existing condition burden based on age, co-morbidity, and gender, we present a simple clinical nomogram (Figure 2) to identify risk of MGCs or death at the time of admission.

Our findings extend prior research on risk factors for traumatic injury and mortality^{15,19-26} by examining a broader outcome, MGCs, in relation to hospital mortality. Inpatient and post-surgical complications are the focus of increasing efforts to improve acute care outcomes¹¹ and are associated with death²⁷, increased cost²⁸, and length of stay.^{29,30} In our series, 14% of all patients suffered at least one complication during hospitalization. Compared to younger patients, older patients had a staggering 34% risk of developing an MGC. Hospital complications are most likely the explanation of why older trauma patients that represent 13% of trauma admissions consume 25% of hospital resources.³¹

In a recent study of hospital complications of trauma injury, which focused on trends in prevalence with increasing age, Adams et al.⁹ found that infectious complications was less common above age 45, attributing this surprising finding to increasing difficulty of diagnosing infection in older patients. In a differing approach, we examined our patients' mortality risk in the presence of each specific complication and identified complications that posed the greatest risk among older adults. We found that older patients with infections are at the greatest risk of dying in relation to younger patients. While we recommend more empirical work in this area, both studies suggest that infection in older trauma patients should be a natural target for future hospital interventions such as early recognition, increased surveillance or preventive efforts.

This study extends prior research on co-morbidity that has focused on specific conditions and their independent contributions to mortality,^{23,32} complications,³³ and on age differences in co-morbidity risk in older patients.³⁴ We instead focused on co-morbidities available to us in the NTDB and conceptualized patients' condition count as their overall burden of pre-existing disease. As expected, we found that co-morbidity contributes to risk of MGCs and death. We also found a steeper relationship between age and MGCs among patients with 3 or more pre-existing conditions compared to those with fewer conditions, with co-morbidity contributing increasing risk above the age of 45. This finding is in agreement with prior observations that mortality in trauma patients increases after the age of 45 years, suggesting a younger age definition for the geriatric population in trauma patients.^{9,12,13} Co-morbidity may be a partial explanation for this increase in risk.

We developed a nomogram (Figure 2) that can be used to stratify risk of death and MGCs based on age, gender, and a simple categorization of co-morbidity count. The potential broader impact of such risk stratification is better identification of aging trauma patients who have the most to gain from in-hospital preventive measures and targeted interventions. This can range from a systems-level approach to preventing the MGCs to a patient-level tool to tailor risk based on known information (age, gender, chronic conditions) at the beginning of the hospitalization, when preventive efforts can feasibly be implemented and be more effective. Such clinical risk tools are supported by current trauma guidelines in older patients.^{12,13} The nomogram we provide might be a starting point to prioritize scarce hospital services and preventive efforts for the individual patients at the greatest risk, e.g., intensified infection-prevention or mobility promotion interventions.

The main strength of this analysis is that we used a very large dataset representing all four geographic quadrants of the United States, spanning trauma centers from levels 1 through 3, with a wealth of data concerning age, co-morbidity, and hospital complications. Despite this vast advantage, we identified a number of limitations inherent to using the NTDB for outcomes research.

Current practice guidelines recommend against the use of injury severity indices in clinical care of individual patients because these are not known until discharge.^{12,13} We did not focus on small differences in ISS for this reason. However, because injury severity is such a strong predictor of death and complications in older hospitalized patients,⁴⁻¹⁰ injury severity was a necessary part of our study design. Our results should be interpreted in light of our study inclusion criteria of moderate-to-severe injury (ISS ≥ 16 , mean ISS=25). Even after limiting by injury severity, the older patients had a slightly lower ISS than the younger patients. Although this difference is likely not clinically relevant, we accounted for it by further controlling for ISS in the analyses. We speculate that the reason for the difference was that older patients are more likely to be hospitalized, and therefore, reported in the NTDB, than younger patients with the same ISS.

Another potential reason is that mechanism of injury differs between the two groups. Low-level falls and blunt injury were more common among the old despite removing low-severity injury from the sample. Future research is needed to develop ways that specific mechanisms of injury and simpler injury severity measures can be identified early in hospital course to stratify risk.

Our study has several additional limitations. The NTDB is a voluntary registry of hospitals, and not a population-based study, with known variation in reporting practices.¹⁴ We attempted to address potential bias against older patients' injuries using analytic weights. Additionally, some hospitals did not report complications or pre-existing conditions. Reporting differences have been shown to change ranking order of complication rates between facilities.¹⁶ Therefore, we only considered patients for complications based on facility-level reporting practice.¹⁶ Using similar logic, we approached multi-morbidity by limiting our analysis to facilities reporting multiple pre-existing conditions. The NTDB also does not include pre-injury functional status, an important geriatric screening tool that prospectively predicts development of hospital complications in older trauma patients.³⁵ Finally, the MGCs we identified should be interpreted as having an association with, rather than cause of, increased mortality. In this retrospective dataset, it is possible that participating institutions were more likely to report infections among older patients who died. Therefore, future prospective and interventional studies focusing on infectious complications in older patients are needed. The risk nomogram that we developed may be useful in combination with screening for pre-injury functional impairment³⁵ and physiologic parameters³⁶ to identify older patients most vulnerable to a complex clinical course.

In summary, we found that older patients with certain specific complications are at differentially higher risk of death due to their age, even after controlling for other known risk factors. We present a risk nomogram to predict death and a new outcome, MGCs. Future work is needed to validate the nomogram prospectively and in population-based studies. The potential impact of this work will be a more efficient approach to the complex clinical needs of older trauma patients with multiple chronic conditions.

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A nomogram predicting those at high-risk of developing death or any mortality-associated geriatric complication (MGC), defined as pneumonia, aspiration pneumonia, compartment syndrome, pulmonary embolism, deep venous thrombosis, pressure ulcer, empyema, failure of wound reduction, abscess, urinary tract infection, fungemia, or bacteremia. To use this nomogram, first count number of pre-existing condition using: dementia, cancer, coronary artery disease, hypertension, congestive heart failure, history of cardiac surgery, coagulopathy, diabetes, neurologic condition, psychiatric condition, pulmonary disease, liver disease, dialysis, drug use, and alcoholism. Next, by gender, locate the risk of MGC (y-axis) according to age (x-axis) and number of co-morbidities (short-dashed curve (no conditions), long dashed curve (1-2 conditions) and solid curve (multimorbid, at least 3 conditions)).

The fine horizontal dotted line illustrates how the nomogram can be used to target the older patients at the highest risk for MGCs, e.g., a quality improvement initiative for all patients above the 30% risk line. Therefore, the patients to target for the initiative would be: 50 year-old men (and older) with at least 3 conditions, 55 year-old men (and older) with at least 1-2 conditions, and all 70 year-old men (and older) should be identified. Similarly, the same level of risk (30%) could be identified for women: 55 year-old women (and older) with at least 3 conditions, 60 year-old women (and older) with at least 1-2 conditions, and all 75 year-old women (and older).

Figure 1.

Flow of data from the National Trauma Data Bank 7.0 (NTDB) to two analytic samples used in this study. ISS=Injury Severity Score.

Figure 2.
Risk of Mortality-Associated Geriatric Complication (MGC) or Death, by Gender, Age and Number of Pre-existing conditions (N=164,486)

Table 1

Sample Characteristics, by Age Group

		Young (age 18-64) N= 223,942	Old (age 65+) N=61,043	P
Male (%)		76%	53%	<.001
Mechanism of injury Blunt trauma (%)		87%	97%	<.001
Motor vehicle collision (%)		56%	32%	<.001
Low-level fall * (%)		3%	22%	<.001
Mean Injury Severity Score (ISS)		25±10.0	23±8.2	<.001
Mean length of stay, days		11.4±16.0	10.0±16.3	<.001
Co-morbidities (pre-injury chronic conditions) **	No co-morbidity	72.3%	42.2%	<.001
	1-2 or more conditions	24.9%	39.5%	<.001
	3+ conditions	5.6%	36.6%	<.001
	Hypertension	5.5%	26.4%	<.001
	Coronary artery disease (CAD)	0.9%	10.4%	<.001
	Diabetes	2.4%	9.9%	<.001
	History of cardiac surgery	3.7%	7.9%	<.001
	Increased bleeding risk (includes “coagulopathy” and “warfarin therapy”)	0.4%	5.6%	<.001
	Neurologic disease (includes “stroke”, “hemiparesis”, “spinal cord disease”, “multiple sclerosis”, and “chronic demyelinating disease”)	1.6%	5.5%	<.001
	Heart failure or cor pulmonale	0.3%	5.0%	<.001
	Dementia (also includes “organic brain syndrome” and “Alzheimer’s Disease”)	0.1%	4.9%	<.001
	Psychiatric disorder	3.1%	3.9%	<.001
	Chronic pulmonary disease (includes “obstructive lung disease” and “asthma”)	2.0%	2.1%	0.563
	Alcohol abuse	4.8%	1.7%	<.001
	Cancer (includes “chemotherapy” and “metastatic disease”)	0.1%	1.0%	<.001
	Dialysis	0.1%	0.6%	<.001
	Cirrhosis	0.3%	0.4%	0.002

		Young (age 18-64) N= 223,942	Old (age 65+) N=61,043	P
	Drug abuse	2.7%	0.1%	<.001

Last column reports P-values for simple unadjusted tests between young and old populations (Chi-squared for categorical outcomes, two-sided t-tests for continuous outcomes).

* Low level was defined as: fall not otherwise specified, same-level fall, fall from low furniture (chair, bed, commode, wheelchair), fall from curb, escalator, or fall against object.

** Prevalence for each co-morbidity is based on all patients reported by facilities who reported at least one patient with that co-morbidity

Table 2

Sample Characteristics, Continued: Unadjusted Prevalence* of Complications, by Age Group

		Young (age 18-64) N= 223,942	Old (age 65+) N=61,043	P
Death		12.6%	24.2%	<.001
Any complication, not including death		13.6%	15.5%	<.001
Infectious complications	Urinary tract infection	3.2%	6.8%	<.001
	Pneumonia	6.0%	5.8%	0.2
	Bacteremia	2.3%	1.9%	<.001
	Aspiration pneumonia	1.3%	1.6%	<.001
	Wound infection	1.5%	0.7%	<.001
	Empyema	0.4%	0.2%	<.001
	Fungemia	0.2%	0.2%	0.4
	Abscess	0.4%	0.1%	<.001
Non-infectious complications	DVT	1.9%	2.3%	<.001
	Cardiac arrest	1.2%	1.9%	<.001
	Renal failure	1.0%	1.9%	<.001
	Acute respiratory distress syndrome	2.2%	1.8%	<.001
	Pressure ulcer	1.3%	1.6%	<.001
	Neurologic, progression of injury	0.9%	1.4%	<.001
	Pneumothorax	1.2%	0.8%	<.001
	Hypothermia	1.1%	0.7%	<.001
	Pulmonary Embolism	0.7%	0.7%	0.2
	Jaundice	0.3%	0.4%	0.08
	Compartment syndrome	0.8%	0.3%	<.001
	Intubation	0.2%	0.2%	0.2
	Reduction/fixation failure	0.2%	0.1%	0.07

Last column reports P-values for simple unadjusted two-sided t-tests for prevalence between young and old populations.

* Prevalence of each complication based only on patients from facilities that reported the complication.

Table 3

Risk of in-hospital mortality among old versus young patients with specific complications

		Mortality among those with complication		aRRR [†] of mortality in old versus young (95% CI)
	N	Young age (18-54)	Old age (65+)	
Any complication	33755	15.3%	29.3%	(1.90 - 2.7)
	Abscess	6.2%	29.2%	(3.62 - 4.52)
Infectious complications	Wound infection	5.8%	19.7%	(3.20 - 3.90)
	Empyema	5.7%	34.3%	(3.13 - 3.84)
	Urinary tract infection	4.9%	15.1%	(3.00 - 3.56)
	Pneumonia	9.6%	30.6%	(2.79 - 3.46)
	Bacteremia	13.0%	37.3%	(2.57 - 2.98)
Non-infectious complications	Aspiration pneumonia	14.3%	33.5%	(2.22 - 3.03)
	Fungemia	15.2%	30.0%	(1.85 - 2.13)
	Reduction/fixation failure	4.0%	15.0%	(3.33 - 3.93)
	Pressure ulcer	6.4%	22.5%	(3.12 - 3.56)
	Deep venous thrombosis	6.9%	18.9%	(2.89 - 3.56)
	Pneumothorax	15.9%	40.8%	(2.51 - 3.74)
	Pulmonary embolism	12.8%	29.7%	(2.38 - 3.18)
	Compartment syndrome	23.3%	51.4%	(1.46 - 2.94)
	Acute respiratory distress syndrome	23.0%	45.1%	(1.67 - 2.2)
	Neurologic, progression of injury	35.9%	57.7%	(1.36 - 1.86)
	Hypothermia	43.8%	62.6%	(1.17 - 1.93)
	Intubation	37.1%	55.6%	(1.15 - 1.97)

	N	Mortality among those with complication		aRRR [†] of mortality in old versus young (95% CI)
		Young age (18-54)	Old age(65+)	
	58	50.0%	66.7%	(1.12 - 1.56)
	2287	43.5%	55.6%	(1.28 - 1.48)
	2316	75.6%	77.7%	(1.03 - 1.11)

Pneumonia and aspiration pneumonia were not mutually exclusive diagnoses. Aspiration pneumonia was differentiated in the NTDB14 by history of aspiration of gastric contents followed by clinical and new radiologic findings within 48 hours, whereas pneumonia required clinical, radiographic, and lab findings. 14

[†]aRRRs are adjusted Relative Risk Ratios, calculated as the ratio of absolute predicted risk of dying for old versus young based on logistic regression models, adjusted for gender, ISS and number of co-morbidities. Samples (N) indicate those with each complication. All models applied sampling weights calculated as the inverse probability of their facility (number of beds, academic institution, reporting isolated hip fractures as trauma) reporting an older patient. Errors were also adjusted for clustering by facility.