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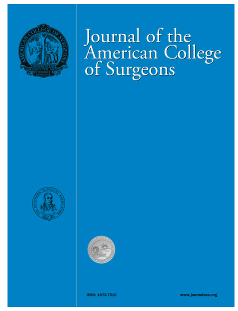

Enhancing the American College of Surgeons NSQIP Surgical Risk Calculator to Predict Geriatric Outcomes

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PII: S1072-7515(19)32120-9

DOI: https://doi.org/10.1016/j.jamcollsurg.2019.09.017

Reference: ACS 9654

To appear in: *Journal of the American College of Surgeons*

Received Date: 11 July 2019

Revised Date: 21 September 2019

Accepted Date: 23 September 2019

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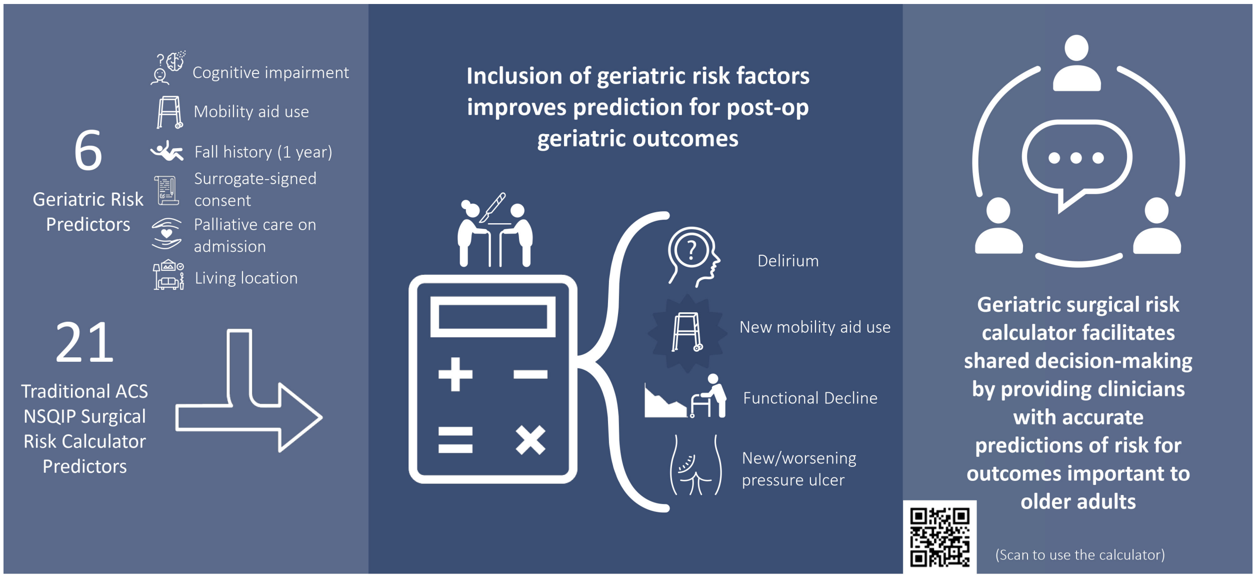

Hornor et al. J Am Coll Surg, January 2020

JACS

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Disclosure Information: Nothing to disclose.

Support: This work was supported in part by the John A Hartford Foundation (grant: 2015-0038), which played no role in or influence upon the study design; data collection, analysis, or interpretation; writing; or decision to submit for publication.

Presented at the American College of Surgeons Clinical Congress Scientific Forum, San Francisco, CA, October 2019.

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Short title: NSQIP Geriatric Surgical Risk Calculator

ABSTRACT

Background The ACS NSQIP Surgical Risk Calculator (SRC) plays an important role in risk prediction and decision-making. We sought to 1) enhance the existing ACS NSQIP SRC with functionality to predict geriatric-specific outcomes and 2) assess the predictive value of geriatric-specific risk factors by comparing performance in outcome prediction using the traditional ACS NSQIP SRC versus models that also included geriatric risk factors.

Study Design Data were collected from 21 ACS NSQIP Geriatric Surgery Pilot Project (GSPP) hospitals between 2014-2017. Hierarchical regression models predicted four postoperative geriatric outcomes (i.e. *pressure ulcer, delirium, new mobility aid use*, and *functional decline*) using the traditional 21-variable ACS NSQIP SRC models and 27-variable models that included six geriatric risk factors (i.e. *living situation, fall history, mobility aid use, cognitive impairment, surrogate-signed consent,* and *palliative care on admission*).

Results Data from 38,048 patients ages ≥ 65 undergoing 197 unique operations across 10 surgical subspecialties were used. Stable model discrimination and calibration between developmental and validation datasets confirmed predictive validity. Models with and without geriatric risk factors demonstrated excellent performance (c-statistics > 0.8) with inclusion of geriatric risk factors improving performance. Of the 21 ACS NSQIP variables, *Current Procedural Terminology (CPT) code, chronic obstructive pulmonary disease (COPD), age, functional dependence, sex, disseminated cancer, diabetes*, and *sepsis* were the strongest risk predictors, while *impaired cognition, fall history*, and *mobility aid use* were the strongest geriatric predictors.

Conclusion The ACS NSQIP SRC can predict four unique outcomes germane to geriatric surgical patients, with improvement of predictive capability after accounting for geriatric risk

factors. Augmentation of ACS NSQIP SRC may enhance shared decision-making to improve the quality of surgical care in older adults.

Abbreviations:

ACS: American College of Surgeons

CMS: Centers for Medicare and Medicaid Services

CPT: Current Procedural Terminology

COPD: Chronic obstructive pulmonary disease

GSPP: Geriatric Surgery Pilot Project

IRB: Institutional Review Board

NSQIP: National Surgical Quality Improvement Program

SRC: Surgical Risk Calculator

INTRODUCTION

Providing an accurate estimate of surgical risk is critical in patient-centered decision-making and informed consent, particularly for older adults. While those 65 and older make up 15% of the population,(1) they account for more than 40%(2) and 33%(3) of all inpatient and outpatient surgeries, respectively. In addition to the increased numbers of older adults undergoing surgery, the timing of their procedures tends to cluster at the end-of-life, reflecting both increased postoperative mortality and potentially inappropriate or non-beneficial surgery. Collectively, this underscores the importance of accurate risk assessment, shared decision-making, and an opportunity to meaningfully impact care.

Recognizing this, the American College of Surgeons (ACS) Geriatric Surgery Task Force launched the Geriatric Surgery Pilot Project (GSPP)(4) in participating ACS National Surgical Quality Improvement Program (NSQIP) hospitals. The GSPP collects data on geriatric-specific patient characteristics and outcomes to better characterize this population's heightened and nuanced surgical vulnerability.(5) These data feed into ACS NSQIP, a robust clinical registry that has been leveraged to inform a number of quality improvement initiatives in addition to the development of the ACS NSQIP Surgical Risk Calculator (SRC). This decision-support tool provides estimates of risk for twelve 30-day outcomes using 21 preoperative risk predictors. More than 1,500 providers per day use the SRC to generate patient-specific risk profiles that assist in preoperative assessment and facilitate goal-directed discussions.(6) Consequently, its role in surgical decision-making has gained national recognition as a quality metric by the Centers for Medicare and Medicaid Services (CMS).(7) The novel variables collected in GSPP highlight an opportunity to enhance the SRC to create a more refined decision-support tool directed at a uniquely vulnerable surgical population.

The objective of this study was to investigate whether geriatric-specific surgical outcomes could be accurately predicted using the data collected from GSPP. To achieve this, our aims were to 1) enhance the existing ACS NSQIP SRC with functionality to predict four geriatric-specific postoperative outcomes (i.e. *pressure ulcer*, *delirium*, *new mobility aid use*, and *functional decline*), and 2) assess the predictive value of six geriatric-specific preoperative risk factors (i.e. *living situation, fall history, use of mobility aid, cognitive impairment, surrogate-signed consent,* and *palliative on admission*) by comparing performance in outcome prediction using the traditional ACS NSQIP SRC versus models that also included geriatric-specific risk factors.

METHODS

Data Source and Collection

Data were obtained from ACS NSQIP and the ACS NSQIP GSPP. ACS NSQIP has been described extensively elsewhere.(8-9) Briefly, it is a multi-institutional data registry of over 200 prospectively-collected variables including patient demographics, comorbidities, preoperative laboratory values, intraoperative events, and 30-day postoperative outcomes for patients undergoing operations of all subspecialties, except trauma and transplant. Reliability and accuracy of data abstracted from medical records are ensured by trained Surgical Clinical Reviewers—who abide by strict data definitions—and supported by ACS audits.(10) In 2014, 21 hospitals responded to a call to participating ACS NSQIP institutions for volunteers to begin collecting 20 unique GSPP variables(5) pertinent to older adult surgical patients, in part to assess the feasibility of collecting these novel measures. As participating ACS NSQIP hospitals, they already had the Surgical Clinical Reviewers required for data abstraction. These 20 variables are categorized by phases of care (i.e. preoperative [n=7], postoperative [n=10], and 30-day postoperative [n=3]) and organized into four geriatric-specific domains (i.e. cognition, function, mobility, and decision-making).

Preoperative Risk Factors

The standard 21 risk predictors of the ACS NSQIP SRC (Table 1) have been described previously(6) and incorporated into our models. Six of the seven preoperative GSPP variables were added as risk predictors. The seventh GSPP variable, *evidence of advance care planning*, was not considered due to a high rate of missing data (>83%).

The six preoperative GSPP variables included were *living situation, fall history within 1 year, use of mobility aid, cognitive impairment, surrogate-signed consent,* and *palliative care on admission*. Patients' *living situation*, meant to capture presence of social support at home or potential caretaker need, was categorized as 'home alone,' 'home with support,' and 'not from home.' The remaining five preoperative variables were binary ('yes' or 'no'). A positive *fall history within 1 year* was defined as experiencing a fall within the year prior to the operation. *Use of mobility aid* indicated whether the patient required an assistive device for mobilization (e.g. cane, walker, wheelchair, scooter). Patients were defined as having *cognitive impairment* if preoperative documentation by a nurse or doctor stated that the patient had dementia or listed predefined descriptors consistent with dementia. 'Yes' for the variable *surrogate-signed consent* was meant to capture severe cognitive impairment rendering the inability to understand informed consent versus 'no' for a self-signed consent. Finally, *palliative care on admission* identified patients who were admitted to the hospital from a hospice setting or had palliative already involved in their care, indicating the diagnosis of a life-threatening condition or shortened life-expectancy.

Rates of missing data for preoperative geriatric variables ranged from 2.16% for *surrogate-signed consent* to 9.99% for *fall history within 1 year*. Missing values were imputed using maximum likelihood,(11-12) consistent with standard ACS NSQIP modeling methodology.(5)

Postoperative Outcomes

The four geriatric-specific, postoperative, binary outcomes modeled in this study were *pressure ulcer, delirium, new mobility aid use,* and *functional decline. Pressure ulcer* was defined as the development of a new pressure ulcer or progression of a present-on-admission pressure ulcer. *Delirium* was captured through descriptive words documented in the medical chart including: "mental status change", "confusion", "disorientation", "agitation", "delirium", "inappropriate behavior", "inattention", "hallucinations", and "combative behavior". *New mobility aid use* was defined as a mobility aid requirement at the time of discharge that was not present on admission (i.e., cane, walker, wheelchair, scooter). Finally, the outcome variable *functional decline* was created by comparing *functional status*—a measure of a patient's need for assistance in performing Activities of Daily Living—at discharge with their preoperative baseline, which is consistent with our previous publication.(13) Patients who were independent preoperatively experienced functional decline if they were classified as partially or totally dependent upon discharge. Partially dependent patients experienced functional decline if they were classified as totally dependent upon discharge.

Inclusion and Exclusion Criteria

Patients 65 years and older who underwent surgery between January 1, 2014 and June 30, 2017 were included. Current Procedural Terminology (CPT) codes with less than 25 cases were excluded to omit uncommonly performed procedures for which adverse event rates are most likely to be unreliably estimated. Cases missing any of the four outcomes of interest were excluded from the models for those outcomes. Patients with the preoperative *functional status* variable coded as 'totally dependent' were excluded from analysis of *functional decline*, and patients with the preoperative *use of mobility aid* variable coded as 'yes' were excluded from analysis of *new mobility aid use*.

Statistical Analysis

Hierarchical, random effects models (SAS GLIMMIX), which account for patients clustered within hospitals and apply a Bayesian-type shrinkage adjustment, were used to model risk prediction.(6) P-value <0.05 determined significance. All statistical analyses were performed using SAS version 9.4.

Model Validation

Holdout cross-validation was performed to assess predictive validity of the four geriatric-specific outcome models.(14) The data were randomly partitioned once into two mutually exclusive datasets containing two-thirds (developmental) and one-third (validation) of the data. The developmental dataset was used to develop all four geriatric outcome models using all 27 risk factors. Model performance was tested by assessing the accuracy in outcome prediction when presented with unknown data, or the validation dataset. This was done by comparing model-fit statistics for the developmental and validation datasets.

Predictive Performance of Models with and without Geriatric Risk Factors

After model validation, four geriatric-specific outcome models (i.e. *pressure ulcer, delirium, new mobility aid use,* and *functional decline*) were developed using the full dataset and two sets of predictors (with and without geriatric-specific risk factors), yielding eight total outcome models. The predictive value of geriatric-risk-factor inclusion was evaluated. This was done by comparing model-fit statistics for models developed with versus without geriatric risk factors.

Model-Fit Statistics

The c-statistic measures discrimination, or a model's ability to accurately classify a binary outcome, such as diseased versus not diseased. Values range from 0.5 to 1.0, with 0.5 equating a model's predictive performance with random chance and 1.0 indicating perfect prediction. Values greater than 0.8 indicate an effective model.(15) While c-statistics are valuable for diagnostic tests, they have limited value as a standalone performance metric for prognostic models, as they are poor at evaluating congruence between predicted and observed probabilities.

The Hosmer-Lemeshow (HL) statistic measures calibration by detecting variation in risk prediction over a range of risk. The HL statistic for an outcome model becomes statistically significant with increasing over- or underestimation of risk for different risk groups, with non-significance reflecting good calibration. Because the HL statistic has a chi-square distribution under the null hypothesis, inconsequential levels of miscalibration often achieve statistical significance without clinical utility in the context of large sample sizes.(16) For this reason, we rely on graphical representation of the HL statistic and, in this study, we constructed 20 sequential risk categories rather than the 10 used for the HL statistic.

Brier scores simultaneously measure both discrimination and calibration. By assessing the accuracy of probabilistic predictions that account for differences between observed events and modeled predictions, it overcomes the limitations faced by the c-statistic. As a model's predicted probabilities align with event and non-event rates, the Brier score will approach 0.0, or perfect prediction.

RESULTS

Over three and a half years (01/01/14 – 06/30/17), 42,296 patients 65 years and older underwent surgery at 21 hospitals enrolled in the ACS NSQIP Geriatric Surgery Pilot Project. CPT codes with less than 25 cases were excluded resulting in 38,048 patients undergoing 197 unique operations across 10 surgical subspecialties (Table 2); these 197 CPT codes represent 18% of the CPT codes in the full dataset. The total number of surgical subspecialties across both full and final datasets remained the same. In order from most to least common by number of cases performed, the 10 surgical subspecialties included are orthopedics, general, peripheral vascular, urology, neurosurgery, gynecology, thoracic, plastics, otolaryngology, and cardiac. The three most common types of procedures performed for each surgeon-reported specialty are found in Table 2. The final sample sizes for each of the four geriatric outcomes of interest (after applying *a priori* inclusion and exclusion criteria) are detailed in the flow diagram (Figure 1).

Model Validation

Holdout cross-validation was used to evaluate the predictive validity of the four geriatric-specific outcome models; model-fit statistics were compared (eTable 1). The average c-statistic was 0.8671 and 0.8689 for the developmental and validation models, respectively. The HL-associated p-values for the developmental and validation datasets of the four outcome models were p=0.0001, with the exception of *pressure ulcer*, which was 0.4903 and 0.3714 for developmental and validation datasets, respectively. The average Brier score was 0.0860 and 0.0857 for the developmental and validation models, respectively. Although the HL statistics were statistically significant for three of the four predicted outcomes, the magnitude of and stability between the c-statistics and Brier scores across developmental and validation models, in addition to the study's large sample sizes, suggest that cross-validation studies assessed the validity and reliability of these four geriatric-specific outcome models.

Predictive Performance of Models with and without Geriatric Risk Factors

Once model validity was assessed, the predictive value of geriatric-risk-factor inclusion in geriatric outcome prediction was evaluated. Model-fit analyses were performed and compared between outcome models with and without geriatric-specific risk factors (Table 3). The c-statistics were slightly higher and Brier scores slightly lower for all outcome models that included geriatric risk predictors. Overall, the discrimination and calibration for both models were similar and acceptable. The HL statistics, represented graphically (Figure 2), are grouped by geriatric-specific outcome and were developed with inclusion of geriatric risk predictors. Each point represents one of the 21 hospitals included in the study and plots the mean observed rates vs. mean predicted rates by geriatric-specific outcome. The middle diagonal line for each of the graphs represents perfect prediction (observed = predicted) with the lines on either side representing the flanking quartiles, or ± 25%. In three of the four outcomes modeled, few points fall outside the ±25% lines, suggesting that the models provide predictions consistent with observed values. The graphical depiction of the fourth outcome, *delirium*, suggests that our model underestimates the rate of postoperative delirium.

Risk Predictors and Outcomes

Of the 21 ACS NSQIP variables, *CPT linear risk, COPD, age, functional dependence, sex, disseminated cancer*, *diabetes requiring insulin*, and *sepsis* were the strongest risk predictors (Table 4). Of the 6 geriatric-specific variables, *impaired cognition*, *fall history within 1 year*, and *mobility aid use* were the strongest predictors (Table 5). Older adult surgical patients in GSPP experienced postoperative outcomes of *pressure ulcer*, *delirium, new mobility aid use,* and *functional decline* at rates of 1.43%, 10.51%, 42.02%, and 37.68%, respectively (Table 5).

Risk Predictors and Outcomes: Traditional ACS NSQIP Variables

Eight of the 21 traditional risk predictors (*CPT linear risk, COPD, age, functional dependence, sex, disseminated cancer, diabetes requiring insulin,* and *sepsis*) demonstrated statistical significance in outcome prediction for $\geq$3 of the 4 geriatric outcomes (Table 4).

CPT linear risk, COPD, and age $\geq$*85* were the only variables assessed that were significantly predictive of increased risk for all four geriatric outcomes. There was a stepwise increase in predicted odds risk for experiencing each of the geriatric outcomes with increasing age.

For *functional dependence,* a 'partially dependent' status was significantly predictive for all four geriatric outcomes. Additionally, being 'totally dependent' was not predictive of *pressure ulcer*. 'Male' *sex* was significantly predictive for all geriatric outcomes except *pressure ulcer*. While 'male' *sex* predicted increased odds of *postoperative delirium*, it was protective for both *new mobility aid use* and *functional decline*. *Disseminated cancer* significantly predicted increased odds for all geriatric outcomes except *pressure ulcer.* Not having *diabetes* (as opposed to being insulin dependent) was significantly protective for all geriatric outcomes except *pressure ulcer.* All three categories of sepsis significantly predicted increased odds for three of the four geriatric outcomes, with increasing severity trending with higher odds.

Risk Predictors and Outcomes: Geriatric-Specific Variables

Of the six geriatric-specific risk factors, each demonstrated a significant association with at least one geriatric-specific outcome; most were significantly associated with multiple outcomes. Preoperative *impaired cognition*, *fall history within 1 year,* and *mobility aid use* were the leading geriatric-specific risk factors to significantly predict increased odds for three of the four geriatric outcomes (Table 5). No single geriatric risk factor predicted all four geriatric outcomes. All six geriatric risk factors significantly predict the outcome *functional decline*. The strongest association found between geriatric risk predictors and outcomes were between preoperative *cognitive impairment* and postoperative *delirium* (OR 2.57, 95%, CI 2.29-2.88).

DISCUSSION

Accurate surgical risk prediction is important, particularly for older adults who not only undergo more surgery but experience poorer outcomes. Existing surgical risk assessment tools are lacking in scope and fail to address the surgical sequela most consequential to these uniquely vulnerable patients. By leveraging both ACS NSQIP and the ACS NSQIP GSPP, both aims of this study were achieved. First, geriatric-specific functionality was developed for the existing ACS NSQIP SRC to predict four additional postoperative outcomes: *pressure ulcer, delirium, new mobility aid use,* and *functional decline*. This tool exhibited excellent discrimination and calibration on model-fit and validity analyses, indicating high reliability and accuracy in outcome prediction across nearly 200 operations and 10 surgical subspecialties (Table 2). Second, comparisons of predictive performance for outcome models that included geriatric-specific risk factors demonstrated improved predictive accuracy.

The outcomes modeled in this study were chosen mindfully to focus on costly and preventable complications commonly affecting older adult surgical patients. Pressure ulcers—arising from malnutrition, immobility, and decreased sensation—affect 2.5 million people, cost $11.6 billion a year (adding an estimated $43,180 per hospital stay), and contribute to 60,000 deaths annually.(17-18) Despite this, pressure ulcers are thought to be largely preventable.(16) Delirium can affect more than 50% of surgical patients,(19) costs upwards of $152 billion annually (adding an estimated $64,421 per patient),(20) is strongly predicted by cognitive impairment (RR 3.5-4.2),(17) can result in persistent and sometimes permanent cognitive decline,(17) and has been associated with a 7.35-fold increase in 5-year mortality (95% CI: 1.49-36.18).(21) Importantly, delirium is preventable 30-40% of the time.(22) Falls are the leading cause of fatal and nonfatal injury in those 65 years and older,(21) and impaired mobility—using new mobility aid use as a proxy—can greatly increase a patient's risk. Annually, falls are responsible for over 800,000 hospital admissions,(21) 27,000 deaths,(23) 95% of hip fractures,(24) and over $50 billion in healthcare costs.(25) Similar to pressure ulcers and delirium, studies suggest that falls in community-dwelling older adults can be reduced by 24-31% with prevention programs.(21, 26) These figures highlight the mounting importance of routine evaluation for geriatric vulnerabilities in the preoperative setting(27) and the beneficial role a geriatric-enhanced decision support tool can play.

While the six geriatric-specific predictors improved model performance, we demonstrate that a substantial portion of the information contained within them is already represented by the 21 traditional risk predictors. This serves as a testament to the effectiveness of the SRC's general design, achieving acceptable accuracy without target-specific predictors for older adult patients as well as for other specific surgical domains. Nevertheless, by designing the SRC interface to require clinician input of the geriatric-specific predictors in order to obtain geriatric-specific outcomes, attention to these factors will hopefully become naturally and increasingly incorporated into the preoperative evaluation over time. Since the 21 participating ACS NSQIP GSPP hospitals abstracted geriatric-specific measures on a voluntary basis, collection burden can be indirectly assessed by rates of missing data.

A geriatric-enhanced SRC will enable clinicians to more effectively assess surgical appropriateness and better guide patient-centered discussions concerning goals of care. Presenting individualized risk profiles for geriatric-specific outcomes to older adult patients and their caregivers helps them make the decision to undergo surgery or not. Ultimately, increasing awareness of geriatric-specific outcomes arms clinicians and their patients with the tools necessary to facilitate the alignment of goals and expectations with surgical plans.

The release of the ACS NSQIP geriatric-enhanced surgical risk calculator coincides with the launch of the ACS Geriatric Surgery Verification (GSV) Program:(28) a national quality improvement program developed to meet the rising need of older adult surgical patients. With input from over 50 stakeholder organizations—representing patients and caregivers, physicians, nurses, other healthcare providers (e.g. care transitions, social workers, pharmacists), hospital groups, payors, and healthcare regulatory bodies—the GSV Program encompasses 32 standards aimed at improving surgical outcomes and developed with the intent of feasible implementation in any hospital performing surgery on older adults. A major focus of the GSV Program is enhancing the pre-operative assessment of patients to better inform goals of care and shared decision-making. By equipping clinicians with more sophisticated risk assessment tools as demonstrated in this study, we can shift the priority from simply fixing a surgical problem to weighing the impact of an operation on patient outcomes and their quality of life.

Limitations

This analysis should be interpreted while considering three important limitations. First, the GSPP variables were collected on a voluntary basis. As such, the sample may not be entirely representative of the ACS NSQIP geriatric population, which may reduce generalizability.

Second, the ACS NSQIP GSPP includes highly engaged hospitals whose feedback has improved data collection over time. Even so, the collection of geriatric-specific variables in a large clinical data registry is unprecedented. While hospitals have been trained on the definitions of geriatric predictor and outcome variables, variability in the level of data scrutiny may influence rates of geriatric-specific outcomes. If a hospital has less scrutiny or sensitivity regarding delirium—that is, failure to positively identify more subtle presentations of delirium—the strength in association between predictor and outcome may be stronger than what is reflected in the data. Even so, the delirium rates in this analysis are on par with published data that utilize validated screens.(29)

Third, while the definition of *functional decline* used was consistent with previous publications by our group,(13) the variable has limited sensitivity in reflecting nuances of functional decline for the older adult population. For example, this study suggests partial dependence was protective for *functional decline*, perhaps because patients who were 'independent' could trigger a functional decline event if they became 'partially-' or 'totally dependent,' whereas those who were 'partially dependent' could only trigger a functional decline event if they became 'totally dependent.' Therefore, the interval distance between 'partially-' and 'totally dependent' is likely larger than that between 'independent' and 'partially dependent,' resulting in decreased sensitivity in truly capturing functional decline. In the future, the GSPP may collect more granular data on functional status to improve the limited sensitivity of this variable.

Fourth, defining *cognitive impairment* as clinically appreciable dementia limits the sensitivity of this variable to capture early cognitive impairment. Therefore, estimates of cognitive impairment and the strength of its association with geriatric-specific outcomes may be underestimated.

Fifth, by nature of selecting from current ACS NSQIP hospitals, data from participating GSPP hospitals may be subject to selection bias. Membership in ACS NSQIP in addition to voluntary enrollment in the GSPP may reflect an above-average interest in quality improvement and geriatric surgery. As a result, it is possible that the geriatric-specific outcomes reflected here may underestimate what is found at hospitals that do not focus on geriatric surgery or quality improvement. While this is a strength from the standpoint of data collection and reliability, it may limit generalizability.

CONCLUSIONS

Data derived from the ACS NSQIP GSPP allow for the development of a geriatric-enhanced SRC to additionally predict four adverse outcomes commonly seen in the older adult surgical population. We have constructed the geriatric-enhanced SRC with inclusion of six geriatric-specific factors to both maximize predictive strength and act as a mechanism to focus clinicians' attention on unique geriatric risk factors that play integral roles in surgical care and postoperative course. This additional functionality can help to advance geriatric surgical care by accurately prognosticating outcomes, informing appropriateness of care, facilitating shared decision-making, and aligning expectations and patient priorities with surgical care plans.

ACKNOWLEDGEMENT

We acknowledge the surgeon champions and surgical clinical reviewers at the participating hospitals of the American College of Surgeons National Surgical Quality Improvement Program Geriatric Surgery Pilot Project for their efforts in data collection and commitment to quality improvement.

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Table 1. Traditional ACS NSQIP and Geriatric-Specific Risk Predictors Used in Geriatric-Specific Outcome Models

Variable	Value	Traditional	Traditional + geriatric
Outcome-specific CPT linear risk	*Continuous*	√	√
Age group, y	65-74; 75-84; ≥85	√	√
Sex	Male, female	√	√
Sepsis 48h preop	None; SIRS; sepsis; septic shock	√	√
Ventilator dependent 48h preop	Yes; no	√	√
Emergency case	Yes; no	√	√
Dyspnea 30d preop	At rest; with moderate exertion; no	√	√
Ascites 30d preop	Yes; no	√	√
History of COPD	Yes; no	√	√
Acute renal failure	Yes; no	√	√
ASA Physical Status Classification	1; 2; 3; 4/5	√	√
Congestive heart failure in 30d preoperatively	Yes; no	√	√
BMI class, kg/m^2	Underweight; normal, overweight; obese 1; obese 2; obese 3	√	√
Steroid use 30d preop	Yes; no	√	√
Hypertension requiring medication	Yes; no	√	√
Current smoker 1y preop	Yes; no	√	√
Diabetes	No; oral; insulin	√	√
Functional status 30d preop	Independent; partially dependent; totally dependent	√	√
Disseminated cancer	Yes; no	√	√
Dialysis	Yes; no	√	√
Living situation	Not from home; home with support; home alone		√
Fall history within 1 year	Yes; no		√
Use of mobility aid	Yes; no		√

Cognitive impairment	Yes; no		√
Surrogate-signed consent	Yes; no		√
Palliative care on admission	Yes; no		√

Outcome-specific CPT linear risk score constructed from 3.5 years of historical NSQIP data
BMI: Underweight <18.5, 18.5<Normal<25, 25<Overweight<30, 30<Obese1<35, 35<Obese2<40, Obese3>40.

CPT, Current Procedural Terminology; SIRS, systemic inflammatory response syndrome; ASA, American Society of Anaesthesiologists

Table 2. Three Most Common Types of Procedures Performed, Categorized by 10 surgeon-Reported Specialties

Specialty, procedure category	CPT code	N*	% overall procedures performed	% procedures in surgical specialty
Orthopedic		15,574	40.9	--
Knee arthroplasty	27446, 27447, 27486, 27487	6362	16.7	40.9
Hip replacement	27125, 27130, 27132, 27134, 27137, 27138	4538	11.9	29.1
Treatment of hip fracture or dislocation	27236. 27244, 27245	3054	8.0	19.6
General		12,165	32	--
Colorectal resection	44140, 44141, 44143, 44144, 44145, 44146, 44150, 44155, 44160, 44204, 44205, 44206, 44207, 44210, 45110, 45119, 45130, 45395,	4303	11.3	35.4
Ventral/incisional/umbilical hernia repair	49560, 49561, 49565, 49566, 49587, 49652, 49653, 49654, 49655,	1103	2.9	9.1
Inguinal and femoral hernia repair	49505, 49507, 49520, 49553, 49650, 49651	1023	2.7	8.4
Peripheral vascular		3,513	9.2	--
Peripheral bypass	35556, 35566, 35571, 35585, 35646, 35654, 35656, 35661, 35665, 35666	811	2.1	23.1
Endarterectomy (carotid, vertebral, subclavian)	35301	1280	3.4	36.4
Endovascular aneurysm repair (aorta, iliac, femoral, popliteal, tibial, peroneal)	34800, 34802, 34803, 34804, 34805, 34825, 37221, 37224, 37225, 37226, 37228	916	2.4	26.1
Urology		2,304	6.1	--
Nephrectomy	50230, 50240, 50543, 50545, 50546, 50548	589	1.6	25.6

Transurethral resection of prostate	52601	417	1.1	18.1
Prostatectomy	55821, 55845, 55866	534	1.4	23.2
Neurosurgery		1,937	5.1	--
Laminectomy, laminotomy, corpectomy	63005, 63015, 63030, 63042, 63045, 63047, 63056, 63081	1159	3.1	59.8
Spinal fusion	22551, 22554, 22558, 22600, 22610, 22612, 22630, 22633	530	27.4	27.4
Incision and excision of central nervous system	61510, 61512	196	0.5	10.1
Gynecology		1,621	4.3	--
Hysterectomy	58150, 58200, 58210, 58260, 58262, 58542, 58548, 58552, 58571, 58573. 58951, 58953, 58954	1408	3.7	86.9
Repair of cystocele or rectocele	57260, 57265	133	0.4	8.2
Genitourinary incontinence procedure	57288	48	0.1	3.0
Thoracic		744	2.0	--
Lobectomy, Pneumonectomy	32480, 32505, 32663, 32666, 32669	600	1.6	80.7
Esophagectomy	43107, 43112, 43117,	135	0.4	18.2
Fundoplication, Paraesophageal hernia repair	43280, 43281, 43282	8	<0.1	1.1
Plastic		88	0.2	--
Skin graft	15734, 15738	47	0.1	53.4
Breast reconstruction	19357	40	0.1	45.5
Debridement of wound, infection, or burn	11044	1	<0.1	1.1
Otolaryngology		72	0.2	--
Thyroidectomy	60220, 60240, 60252, 60271	37	0.1	51.4
Modified radical neck dissection	38724	16	<0.1	22.2

Parathyroidectomy	60500	14	<0.1	19.4
Cardiac		30	0.1	--
Coronary artery bypass graft	33533	30	0.1	100

* N=total number of cases for the indicated CPT codes. Only CPTs with a minimum of 25 cases were included in this study.

Table 3. Model-Fit Statistics for Comparative Model Performance of those Developed Without (Traditional) and with (Traditional + Geriatric) Geriatric Risk Factors

Outcome	N	Event, n (%)	C-statistic		Hosmer-Lemeshow statistic, p value)		Brier Score	
			Traditional	Traditional + geriatric	Traditional	Traditional + geriatric	Traditional	Traditional + geriatric
Pressure ulcer	36,335	521 (1.4)	0.8428	0.8477	0.2761	0.2761	0.0135	0.0134
Delirium	37,035	3,893 (10.5)	0.8409	0.8569	0.0002	0.0002	0.0759	0.0723
New mobility aid use	24,097	10,125 (42.0)	0.9329	0.9343	0.0001	0.0001	0.0956	0.0949
Functional decline	36,354	13,697 (37.7)	0.8233	0.8330	0.0001	0.0001	0.1655	0.1621

C-statistics represent improved discrimination as they approach 1; Brier scores represent improved calibration as they approach 0. As chi2 values are uninformative without associated degrees of freedom, only Hosmer-Lemeshow (HL) statistic associated p-values are displayed. A list of Traditional and Geriatric risk factors can be found in Table 1. Refer to Figure 1 for outcome sample size (n) calculation.

Table 4. Risk-adjusted odds ratios (OR) for the association of traditional risk predictors with geriatric-specific outcomes without (21) and with (27) geriatric predictors.**

Variable, category	Geriatric outcome model (#Risk Predictors), OR							
	PU(21)	PU(27)	D(21)	D(27)	MAU(21)	MAU(27)	FD(21)	FD(27)
Outcome-specific CPT linear risk	3.64*	3.46*	2.75*	2.12*	2.81*	2.78*	2.80*	2.60*
Age group								
65-74 y	-	-	-	-	-	-	-	-
75-84 y	1.23	1.13	1.97*	1.81*	1.69*	1.65*	1.47*	1.36*
≥85 y	1.60*	1.25	3.15*	2.29*	2.97*	2.72*	2.59*	1.87*
Sex								
Female	-	-	-	-	-	-	-	-
Male	1.12	1.19	1.17*	1.28*	0.77*	0.80*	0.84*	0.91*
Sepsis 48h preop								
None	-	-	-	-	-	-	-	-
SIRS	1.58*	1.53*	2.06*	2.00*	1.29	1.27	1.73*	1.57*
Sepsis	1.25	1.29	2.24*	2.48*	2.00	2.03*	3.11*	3.26*
Septic Shock	2.05*	2.00*	3.04*	2.54*	1.30	1.30	6.26*	5.28*
Ventilator dependent 48h preop								
No	-	-	-	-	-	-	-	-
Yes	1.36	1.41	0.96	0.81	1.54	1.28	2.57*	2.15*
Emergency case								
No	-	-	-	-	-	-	-	-
Yes	1.41*	1.39*	0.99	0.95	1.10	1.02	0.86*	0.76*
Dyspnea 30d preop								
At Rest	-	-	-	-	-	-	-	-
With moderate exertion	0.67	0.70	1.67*	1.71*	0.60	0.58	0.91	0.89
No	0.84	0.87	1.40	1.40	0.48*	0.47*	0.78	0.78
Ascites 30d preop								
No	-	-	-	-	-	-	-	-
Yes	1.63	1.67	0.96	1.09	1.17	1.16	2.29*	2.41*
Acute renal failure								

No	-	-	-	-	-	-	-	-
Yes	0.62	0.63	1.13	1.27	0.51	0.48	1.77	1.74
History of COPD								
No	-	-	-	-	-	-	-	-
Yes	1.39*	1.36*	1.15*	1.19*	1.31*	1.31*	1.21*	1.18*
ASA physical status classification								
1	-	-	-	-	-	-	-	-
2	1.80	1.74	1.25	1.19	0.87	0.87	1.42*	1.36*
3	2.63	2.39	2.14*	1.76	1.08	1.05	2.03*	1.73*
4/5	4.35	3.84	3.49*	2.68*	1.28	1.23	3.26*	2.52*
Congestive heart failure 30d preop								
No	-	-	-	-	-	-	-	-
Yes	1.62*	1.57*	0.86	0.79	1.17	1.08	1.32*	1.19
BMI Class, kg/m^2								
Obese 3	1.70*	1.63*	1.17	1.20	1.17	1.18	1.21*	1.18*
Obese 2	1.66*	1.65*	1.13	1.12	1.08	1.09	1.07	1.05
Obese 1	-	-	-	-	-	-	-	-
Overweight	1.05	1.07	1.27*	1.26*	0.89*	0.88*	1.05	1.05
Normal	1.36*	1.35*	1.45*	1.38*	0.94	0.92	1.09*	1.05
Underweight	1.75*	1.70*	1.46*	1.29*	1.02	0.99	1.13	0.99
Steroid use 30d preop								
No	-	-	-	-	-	-	-	-
Yes	1.19	1.16	0.94	1.00	1.15	1.14	1.11	1.08
Hypertension requiring medication								
No	-	-	-	-	-	-	-	-
Yes	1.26*	1.25*	1.00	1.04	1.13*	1.13*	1.02	1.03
Current smoker 1y preop								
No	-	-	-	-	-	-	-	-
Yes	1.09	1.08	1.26*	1.30*	1.12	1.11	1.04	1.02
Diabetes								
No	0.82	0.86	0.66*	0.67*	0.79*	0.80*	0.74*	0.80*
Oral	0.88	0.90	0.72*	0.71*	0.99	0.99	0.77*	0.81*

Insulin	-	-	-	-	-	-	-	-
Functional Status 30d preop								
Independent	-	-	-	-	-	-	-	-
Partially dependent	2.25*	1.80*	2.75*	1.49*	1.54*	1.22	0.05*	0.02*
Totally dependent	1.37	1.14	2.30	0.84	0.09	0.06	N/A	N/A
Disseminated cancer								
No	-	-	-	-	-	-	-	-
Yes	1.37	1.44	1.10*	1.22*	1.26*	1.22*	1.22*	1.22*
Dialysis								
No	-	-	-	-	-	-	-	-
Yes	1.88*	1.85*	0.90	0.97	1.67*	1.65*	1.26	1.23

BMI: Underweight <18.5; 18.5<Normal<25; 25<Overweight<30; 30<Obese1<35; 35<Obese2<40; Obese3>40.

*Significant value, where p<0.05.

PU, pressure ulcer; D, delirium; MAU, new mobility aid use; FD, functional decline; ASA, American Society of Anaesthesiologists

Table 5. Association of Geriatric-Specific Risk Predictors with Geriatric-Specific Outcomes (Risk Adjusted for Traditional + Geriatric Risk Predictors)

Variable	Pressure ulcer	Delirium	New mobility aid use	Functional decline
Events / sample size (%)	521 / 36,335 (1.4)	3,893 / 37,035 (10.5)	10,125 / 24,097 (42.0)	13,697 / 36,354 (37.7)
Preoperative living situation, OR (95% CI)				
Not from home vs home alone	0.84 (0.58-1.22)	1.03 (0.85-1.24)	1.03 (0.66-1.60)	1.74 (1.40-2.17)*
Home with support vs home alone	0.85 (0.68-1.05)	0.93 (0.85-1.02)	0.87 (0.79-0.96)*	0.87 (0.82-0.92)*
Fall history within 1y before operation, OR (95% CI)	1.20 (0.97-1.49)	1.53 (1.38-1.70)*	1.84 (1.60-2.12)*	1.50 (1.36-1.58)*
Use of preoperative mobility aid, OR (95% CI)	1.67 (1.35-2.06)*	1.46 (1.34-1.59)*	N/A	1.67 (1.58-1.77)*
Preoperative cognitive impairment, OR (95% CI)	0.94 (0.70-1.25)	2.57 (2.29-2.88)*	1.21 (1.02-1.43)*	1.79 (1.60-2.00)*
Surrogate-signed consent, OR (95% CI)	1.30 (0.96-1.75)	1.82 (1.59-2.08)*	1.14 (0.88-1.50)	1.89 (1.61-2.21)*
Palliative care on admission , OR (95% CI)	1.15 (0.44-3.02)	0.80 (0.46-1.38)	2.58 (0.65-10.26)	2.13 (1.18-3.86)*

*Significant

OR, odds ratio

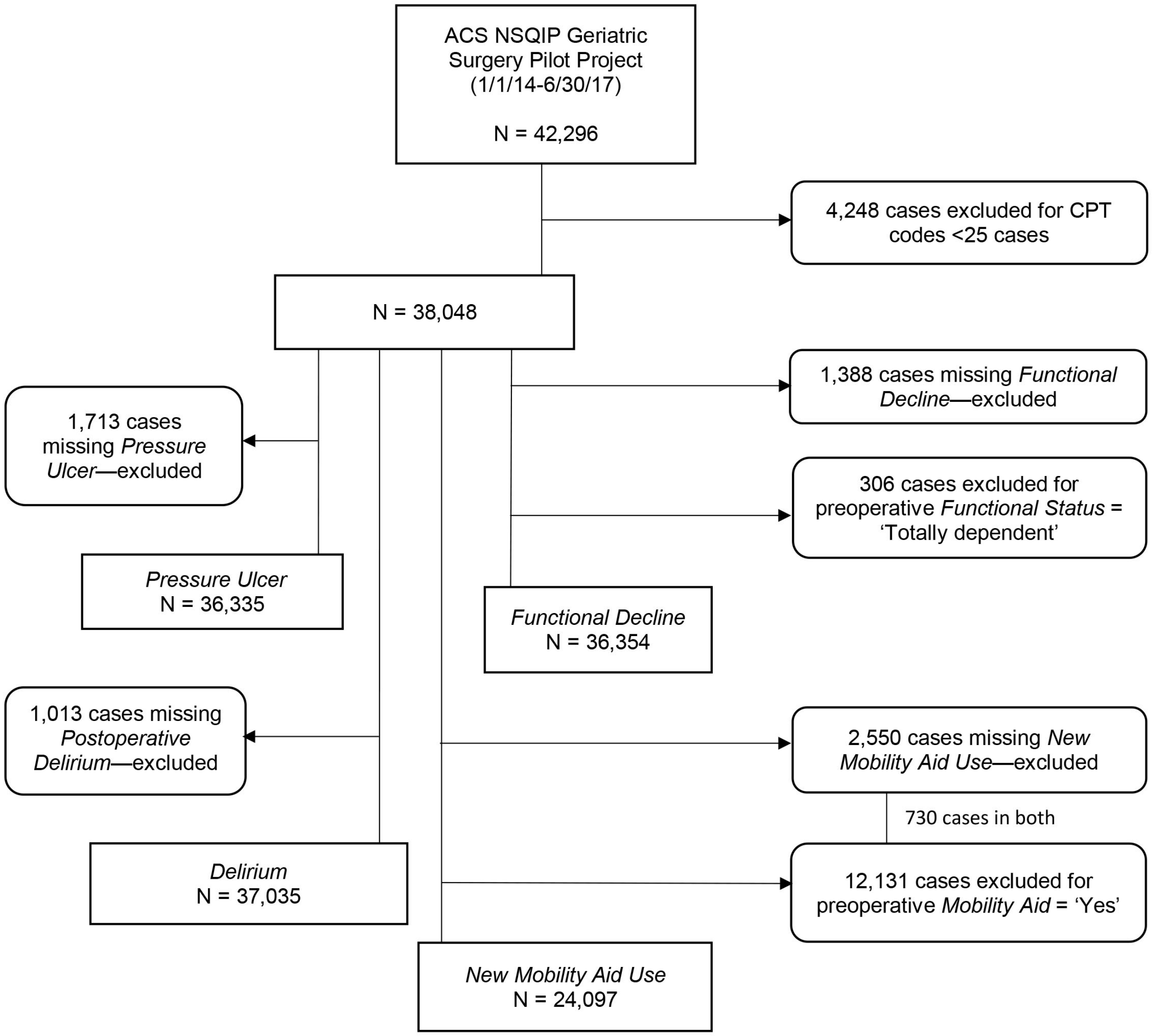
Figure legend

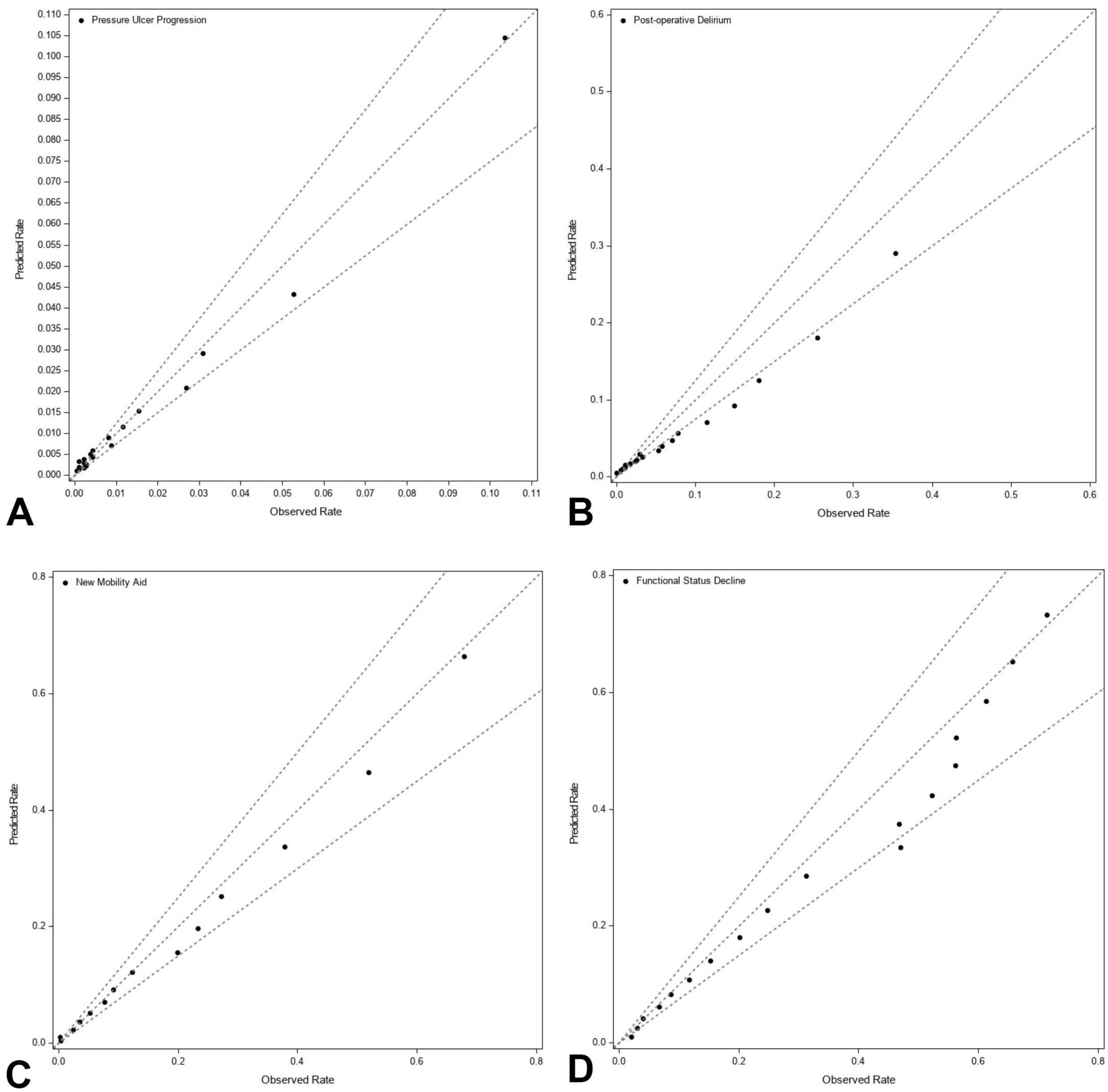
Figure 1 Flow diagram of inclusion and exclusion criteria for outcome-specific sample size calculation

Figure 2 Graphical representation of Hosmer-Lemeshow statistics for 4 geriatric outcome models developed with inclusion of geriatric risk predictors, plotting the mean observed rates vs mean predicted rates for current procedural terminology (CPT) codes; (A) pressure ulcer, (B) delirium, (C) mobility aid use, and (D) functional decline. Only codes with at least 25 cases are included. By outcome, the points represent each of the 21 hospitals included in the analyses. The middle diagonal line represents perfect prediction (observed = predicted) with the lines on either side representing the flanking quartiles, or ± 25%.

Precis

The American College of Surgeons NSQIP Surgical Risk Calculator is an important decision support tool. This study aimed to enhance its functionality to predict 4 novel geriatric-specific outcomes and demonstrated that the addition of 6 geriatric-specific risk factors improved predictive performance when compared to the traditional surgical risk calculator.


ACS NSQIP Geriatric Surgery Pilot Project (1/1/14-6/30/17)
N = 42,296
4,248 cases excluded for CPT codes <25 cases
N = 38,048
1,713 cases missing *Pressure Ulcer*—excluded
Pressure Ulcer
N = 36,335
1,388 cases missing *Functional Decline*—excluded
306 cases excluded for preoperative *Functional Status* = 'Totally dependent'
Functional Decline
N = 36,354
1,013 cases missing *Postoperative Delirium*—excluded
Delirium
N = 37,035
2,550 cases missing *New Mobility Aid Use*—excluded
730 cases in both
12,131 cases excluded for preoperative *Mobility Aid* = 'Yes'
New Mobility Aid Use
N = 24,097


Pressure Ulcer Progression
Predicted Rate
Observed Rate
A
Post-operative Delirium
Predicted Rate
Observed Rate
B
New Mobility Aid
Predicted Rate
Observed Rate
C
Functional Status Decline
Predicted Rate
Observed Rate
D

eTable 1. Cross-Validation Model-Fit Statistics for Developmental and Validation Datasets of Four Geriatric Outcome Models Developed with the Inclusion of Geriatric Risk Predictors

Outcome	N	C-statistic		Hosmer-Lemeshow statistic, p value		Brier Score	
		Developmental	**Validation**	**Developmental**	**Validation**	**Developmental**	**Validation**
Pressure ulcer	36,335	0.8440	0.8517	0.4903	0.3714	0.0128	0.0132
Delirium	37,035	0.8568	0.8568	0.0001	0.0001	0.0712	0.0711
New mobility aid use	24,097	0.9342	0.9344	0.0001	0.0001	0.0998	0.0986
Functional decline	36,354	0.8334	0.8326	0.0001	0.0001	0.1603	0.1597

C-statistics represent improved discrimination as they approach 1; Brier scores represent improved calibration as they approach 0. As chi^2 values are uninformative without associated degrees of freedom, only Hosmer-Lemeshow (HL) statistic associated p values are displayed. Holdout cross-validation was performed to assess predictive validity of the 4 geriatric-specific outcome models. The data were randomly partitioned once into 2 mutually exclusive datasets containing two-thirds (developmental) and one-third (validation) of the data. The developmental dataset was used to develop all 4 geriatric outcome models using all 27 risk factors.