Role of Patient- and Surgery-Specific Risk in Receipt of Outpatient Preoperative Testing

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Abstract

Objective—To determine the independent association of patient- and surgery-specific risk with receipt of outpatient preoperative testing.

Methods—Using administrative data from 2010–2013 (Marketscan® Commercial Claims and Encounters), we constructed a retrospective cohort of 678,368 privately-insured, non-elderly US adults who underwent one of ten operations, including one lower-risk and one higher-risk operation from five surgical specialties. Outcomes were receipt of nine outpatient tests in the 30 days before surgery and cost of those tests. Patient-specific risk was based on Revised Cardiac Risk Index (RCRI) and, alternatively, the Charlson Comorbidity Index (CCI). Surgery-specific risk was based on operation (higher- versus lower-risk within each specialty). Multivariable logistic regression models were constructed to measure the independent association of patient- and surgery-specific risk with the receipt of tests.

Results—Receipt of tests ranged from 0.9% (pulmonary function tests) to 46.8% (blood counts), and 65.2% of patients received at least one test. Mean cost per patient for all tests was $124.38. Higher RCRI was strongly associated (Odds Ratio (OR) >2) with receipt of stress tests and echocardiograms, and more modestly associated [OR <2] with receipt of most other tests. Undergoing higher-risk operations was strongly associated with receipt of most tests. Results were similar using the CCI for patient-specific risk.

Conclusion—Surgery-specific risk is strongly associated with receipt of most preoperative tests, which is consistent with preoperative testing protocols based as much or more on the planned operation as on patient-specific risk factors. Whether this pattern of preoperative testing represents optimal care is uncertain.

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Conflicts of Interest: The authors report no conflicts of interest.

Keywords

Preoperative testing; non-cardiac surgery; overuse

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1. INTRODUCTION

In an era of increased attention on overuse of medical services, preoperative testing has come under scrutiny.[1–4] Evidence that preoperative testing improves outcomes is lacking[5,6] and testing practices vary widely.[7,8] Many have raised concerns that preoperative testing is overused.[1,2] Choosing Wisely recommendations to perform fewer preoperative tests were made by numerous professional societies, including the American Society of Anesthesiologists and the American College of Surgeons.[9]

Recent clinical guidelines have recommended that preoperative testing not be performed "routinely."[10–12] The American Society of Anesthesiologists Practice Advisory for Preanesthesia Evaluation recommends that tests be ordered selectively "after consideration of specific information obtained from sources such as medical records, patient interview, physical examination, and the type or invasiveness of the planned procedure and anesthesia."[10] The American College of Cardiology/American Heart Association (ACC/AHA) guidelines on perioperative cardiovascular evaluation recommend against testing for coronary artery disease when the combined surgical and patient characteristics predict a risk of a major adverse cardiac event of less than 1%.[11]

While guidelines recommend that patient- and surgery-specific risk assessment should guide preoperative testing, how these factors affect testing in actual practice is unknown. Several recent studies have examined predictors of preoperative testing, but these studies were limited to a single test,[13–15] or focused exclusively on low-risk operations and procedures, [7,8,16,17] precluding the ability to assess the contribution of surgery-specific risk. In this study, we aimed to measure the independent association of patient- and surgery-specific risk with the receipt of preoperative tests in a range of operations using a nationwide data source.

2. MATERIALS AND METHODS

2.1 Data

We used MarketScan® Commercial Claims and Encounters (Truven Health Analytics) from 2010–2013. MarketScan® collects utilization and expenditure data for employees, retirees, and their dependents from more than 250 medium- and large-sized employers and health plans from across all 50 states and the District of Columbia. The database includes data from inpatient and outpatient visits for approximately 43 to 55 million beneficiaries in each of the years we examined, which represents approximately twenty percent of all privately insured individuals in the US. This study was exempted by the Johns Hopkins University Institutional Review Board.

2.2 Selection of Operations

To assess the effect of surgery-specific risk on preoperative testing, we chose two operations from five surgical specialties: general, vascular, orthopedic, urologic, and gynecologic. Our goal was to choose two common operations with gradient of surgery-specific risk (i.e., one "lower-risk" and one "higher-risk" operation in each specialty, not necessarily "low-risk" and "high-risk"). There are no universally accepted methods for classifying the intrinsic surgery-specific risk of different operations. We considered adopting the three-category classification system used in some versions of the ACC/AHA guidelines (i.e., of low-, intermediate-, and high-risk), but this schema is difficult to operationalize due to limited examples of operations within each category, and the ACC/AHA guidelines have moved away from this system in their most recent guidelines.[11] Therefore, we opted to use the Johns Hopkins Surgical Classification System (JHSCS), which classifies operations into five risk categories based on physiologic factors such as expected blood loss and fluid shifts.[18] While the JHSCS includes a fairly comprehensive list of operations in each category, we had to estimate the category for several operations that were not listed. However, we chose operations with high face-validity for having qualitatively different intrinsic risks (e.g., cholecystectomy has higher risk than hemorrhoidectomy, and total prostatectomy has higher risk than transurethral resection of the prostate). The higher-risk operations included laparoscopic cholecystectomy, carotid endarterectomy, total prostatectomy, total knee arthroplasty, and hysterectomy. The lower-risk operations included hemorrhoidectomy, peripheral artery angioplasty or stent, transurethral resection of the prostate, shoulder and knee arthroscopies, and tubal ligation. The *Current Procedural Terminology* codes and the JHSCS category for each operation are listed in Appendix Table 1.

Our intent was to examine elective operations, as patients undergoing urgent or emergent operations may be less likely to undergo outpatient preoperative testing. Therefore, we included only operations performed on an outpatient basis for each of the lower-risk operations and laparoscopic cholecystectomy (the higher-risk general surgery operation). For the other higher-risk operations, we included those performed on an outpatient basis or on the first day of a hospital admission.

2.3 Study Population

We included beneficiaries aged 18 to 64 years who were continuously enrolled in a health plan for one year prior to their operation and had at least one outpatient visit with a primary care provider between one month and one year prior to their operation. If patients had more than one eligible operation, we only included the first they received.

To identify comorbid diagnoses, we searched for *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9) diagnostic codes in inpatient and outpatient records in the 12 months prior to the operation (included ICD-9 codes are listed in Appendix Table 2). As the measure of patient-specific risk, we calculated the revised cardiac risk index (RCRI), similar to previous studies using administrative data.[19–21] Diabetes mellitus, ischemic heart disease, chronic kidney disease, congestive heart failure, and cerebrovascular disease were each assigned 1 point. For this study, we did not assign RCRI points for "high-

risk" operations because we wanted to use a separate variable to account for surgery-specific risk, so the possible RCRI ranged from 0 to 5.

2.4 Outcomes

The primary outcome was receipt of nine tests performed as an outpatient during the 30 days before surgery. Included tests were blood counts, metabolic panels, coagulation tests, urinalyses, electrocardiograms, stress tests, echocardiograms, chest radiographs, and pulmonary function tests performed in an outpatient setting (*Current Procedural Terminology* codes are listed in Appendix Table 3).

The costs reported in the analysis are the total payments (not charges), which includes the payments by insurance and by patients. All costs were inflation-adjusted to 2013 dollars using the Consumer Price Index for medical care services.[22] To deal with outliers, we replaced negative costs with $0, and we truncated high costs at the 99th percentile for each test.

Since we were not able to determine the indication for testing, we also assessed use of each test in the 180 days (six 30-day blocks) prior to the operation to compare use of tests in the preoperative month with the baseline use of each test in earlier months.

2.5 Statistical Analyses

We tabulated the percentage of patients who received each test prior to their operation. We tabulated the mean cost for each test for patients who received the test, as well as the mean cost per test distributed among all patients.

We used separate logistic regression models to estimate the odds of a patient receiving each preoperative test dependent on patient-specific risk (RCRI), surgery-specific risk (lower-risk or higher-risk surgery), and potential confounders (surgical specialty, age, and sex). Due to the small number of patients with RCRI scores greater than two, we collapsed the RCRI into a three-level categorical variable (0, 1, 2). We accounted for clustering of patients within surgical specialties when calculating the variance. Additionally, we performed two sensitivity analyses and an exploratory analysis. First, we repeated the analyses using the Charlson Comorbidity Index (CCI)[23] as the measure of patient-specific risk instead of using the RCRI. Second, we repeated the analyses using the RCRI as the measure of patient-specific risk and also included indicator variables for each of the eight additional comorbidities (hypertension, hyperlipidemia, liver disease, thromboembolism, chronic pulmonary disease, atrial fibrillation, anemia, and dementia) that may affect the actual or perceived need for a preoperative testing. Finally, as an exploratory analysis, we repeated the main analyses including an interaction term between patient-specific and surgery-specific risk variables. We used STATA version 14.0 for all statistical analyses.

3. RESULTS

A total of 678,368 patients were in the final analysis (Table 1). The median age was 51 years, 58.9% were female, and 43.3% underwent the higher-risk operations. Hypertension (39.4%) and hyperlipidemia (37.9%) were the most common comorbidities, and diabetes

was the most common RCRI comorbidity (14.0%). A majority of patients had no RCRI comorbidities (79.1%).

The proportion of patients receiving each preoperative test and costs are shown in Table 2. The most common preoperative test received were blood counts (46.8% of patients), while the least common test were pulmonary function tests (0.9% of patients). Nearly two-thirds (65.2%) of patients received at least one test. Among patients who received the test, stress tests were the most expensive test ($932.65) and urinalyses were the least expensive ($13.60). Mean cost for all tests was $124.38 per patient; blood counts, metabolic panels, coagulation tests, electrocardiograms, and chest radiographs each contributed between $13 and $26 per patient, while the other four tests contributed less than $10 each.

The receipt of each test during the six months before surgery is shown in Figure 1. For each test, use in the preoperative month was substantially higher than any of the preceding five months.

The association of patient- and surgery-specific risk with the receipt of preoperative tests is shown in Table 3. Higher RCRI was modestly associated [odds ratio (OR) greater than 1.0 and less than 2.0] with the receipt of most of the tests. The notable exceptions were stress tests and echocardiograms, where higher RCRI was strongly associated (OR greater than 2.0) with use. Undergoing the higher-risk operations was strongly associated with receipt of most of the tests.

The results of the sensitivity analyses are shown in Appendix Tables 4 and 5. Using the CCI instead of the RCRI yielded similar results, with the notable exception that CCI had a strong association with receipt of pulmonary function tests (CCI = 0 reference; OR 4.64 (95% CI 4.37–4.93) for CCI = 1, OR 6.33 (95% CI 5.90–6.80) for CCI 2). Including the non-RCRI comorbidities in the models using RCRI as the measure of patient-specific risk yielded similar results for the association between surgery-specific risk and receipt of preoperative tests, but slightly attenuated the association between patient-specific risk and receipt of each preoperative test. The results of the exploratory analyses are shown in Appendix Tables 6 and 7. Including an interaction term between patient-specific and surgery-specific risk variables led to qualitatively similar results.

4. DISCUSSION

In this analysis of privately insured, non-elderly patients undergoing ten common operations, the most common preoperative tests were metabolic panels, blood counts, and electrocardiograms, which were performed before nearly half of the operations. Higher patient-specific risk was only modestly associated with receipt of most preoperative tests, while higher surgery-specific risk was strongly associated with receipt of most of the tests.

The prevalence of preoperative tests in the current study is generally consistent with the recent literature. For example, Kerr and colleagues found that 0.7% of VA patients and 2.1% of Medicare patients had stress testing prior to low-risk surgical procedures,[13] and Benarroch-Gampel and colleagues found that 54% of patients underwent at least one test prior to hernia repair.[16] However, our study provides a nationally representative estimate of

the prevalence of preoperative tests across a wider range of elective operations and estimates the cost contributions of each test.

Our finding that undergoing one of the higher-risk operations was strongly associated with receipt of preoperative tests can be interpreted in several ways. It is possible that clinicians performing preoperative evaluation are incorporating the surgery-specific risk into an overall risk estimate that guides the intensity of preoperative testing, which would be consistent with current guideline recommendations. Alternatively, there may be a threshold effect for some clinicians or hospitals, where a standardized evaluation including routine testing is performed for all patients undergoing what is considered to be a major operation. For example, guidelines published by the National Institute for Health and Care Excellence (NICE) in the United Kingdom recommend that all adults undergoing "major surgery" have complete blood counts tested prior to surgery, regardless of age and comorbidities.[24] Guidelines for preoperative testing may be established by institutions who take a similar approach to NICE and require routine tests for certain operations.[18] A recent qualitative study of surgeons supports the notion that a large proportion of preoperative testing is driven by hospital and anesthesiology requirements, which is in turn determined by the what operation is planned.[25]

Our findings for the group of patients undergoing general surgery procedures—laparoscopic cholecystectomy and hemorrhoidectomy—are particularly illustrative. Over half of the patients undergoing laparoscopic cholecystectomy received metabolic panels and blood counts and over one-third received an ECG, more than double the corresponding rates among patients undergoing hemorrhoidectomy. Previous studies have shown that laparoscopic cholecystectomy is generally not a high-risk operation, with operative mortality rates much lower than one percent.[26,27] However, laparoscopic cholecystectomy is typically performed in an operating room under general anesthesia, in contrast to hemorrhoidectomy, which is often performed in an office setting under local anesthesia. Widespread use of the RCRI may create confusion about the risk of laparoscopic cholecystectomy, since as an intraperitoneal operation, it would be classified as a high-risk operation by the RCRI.[28] Alternatively, some hospitals may adhere to policies requiring all patients undergoing general anesthesia in an operating room setting to have certain preoperative tests, resulting in overuse of testing before low-risk operations like laparoscopic cholecystectomy.

Our findings need to be interpreted in light of the limited evidence regarding the effects of preoperative testing on surgical outcomes, which this study was not able to address. Some commentators have argued that preoperative testing is overused in many situations,[1,2] largely based on observational studies showing that routine tests are infrequently abnormal and unlikely to change management. However, except for cataract surgery,[29] high-quality evidence demonstrating the safety of forgoing preoperative testing has proven difficult to generate.[30] Preoperative testing is also associated with potential harms, such as invasive procedures to follow-up false positive results or delaying the planned operation.[3] Much of the recent attention on potential overuse of preoperative testing has focused on low-risk patients or those undergoing low-risk operations. While the benefit-risk ratio of preoperative testing may be particularly unfavorable in these situations, it may not be favorable for patients undergoing higher risk operations either. The fact that none of the tests were

received by more than half of patients in our study suggests that a substantial number of clinicians may not believe that routine preoperative testing is helpful. More research into which patients actually benefit from preoperative testing is needed.

Despite concerns about potential overuse, the uncertainty about the effectiveness of preoperative tests and office visits means that there may be underuse of some preoperative tests as well. For example, some guidelines recommend (on the basis of expert opinion) performing a urinalysis prior to surgical implantation of foreign material or invasive urologic procedures.[12] We found that only about half of patients undergoing knee arthroplasty or one of the urologic procedures had a urinalysis in the 30 days prior to surgery.

The cumulative cost of preoperative evaluation has been estimated to be between $3 billion[31] and $40 billion.[32] Our study was not designed to provide a precise estimate of the cumulative cost of preoperative testing, but there are approximately 27 million operations performed in the US annually[33] and we found that the total cost of tests in the preoperative month to be over $120 per patient, so it supports an estimate of cumulative cost on the lower end of this range. Given this high cost, even a moderate amount of overuse could result in a significant amount of unnecessary spending. Our results highlight that only a small fraction of total spending results from the more expensive tests such as stress tests, which have received so much attention.[13,14] Furthermore, solely focusing on potential overuse in low-risk operations overlooks the greater resources in preoperative testing before higher-risk operations, where overuse may also be present. Additional research is needed to determine whether the current state of preoperative testing represents overuse, underuse, or appropriate care.

One limitation of this research relates to identifying preoperative tests in claims data. We considered any outpatient test done within 30 days of surgery to be a preoperative test, but each of the tests we examined has numerous uses other than as preoperative testing, and some of the tests we identified may have been unrelated to the upcoming operation. However, the use of each test was lower in the months leading up to the preoperative month than in the preoperative month, suggesting that a majority were related to the upcoming operation. We were also unable to determine who ordered the tests. Dedicated preoperative clinics have been associated with decreased preoperative testing,[34] but since many preoperative clinics do not bill those visits, they are not captured in claims data. Therefore, we were not able to determine whether the pattern of testing found in this study holds true for patients seen in preoperative clinics.

This study had several other limitations. Our primary analysis used the RCRI as the measure of patient-specific risk. The RCRI was developed as a measure of cardiac risk, so it may not be the ideal measure of more generic patient-specific risk. For example, cardiac death represents only about one-third of perioperative mortality,[21] and the RCRI has not been shown to be highly predictive of total perioperative mortality.[35] However, we obtained similar results when we used the CCI or included additional non-RCRI risk factors in our models, which suggests that our results are robust. Additionally, our population included only privately-insured, non-elderly patients in the US, so our findings may not apply to other populations. Finally, the nature of insurance claims data limits the ability to ascertain

postoperative outcomes, particularly for outpatient operations where there is not even an opportunity to observe inhospital complications that might be captured by insurance claims, so we were unable assess the association of preoperative tests with postoperative outcomes.

5. CONCLUSIONS

This study found that patient-specific risk is modestly associated with receipt of most preoperative tests, while surgery-specific risk is more strongly associated with most of the tests. This pattern suggests that preoperative testing is based as much or more on the planned surgical procedure as it is on patient-specific risk factors. While this pattern of preoperative testing is generally adherent to guidelines that recommend that both patient-specific and surgery-specific factors guide the preoperative evaluation, more research examining the effect of preoperative testing on postoperative outcomes are needed to determine whether current practice represents optimal care.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

LIST OF ABBREVIATIONS

ACC/AHA	American College of Cardiology/American Heart Association
CCI	Charlson Comorbidity Index
JHSCS	Johns Hopkins Surgical Classification System
OR	Odds Ratio
RCRI	Revised Cardiac Risk Index

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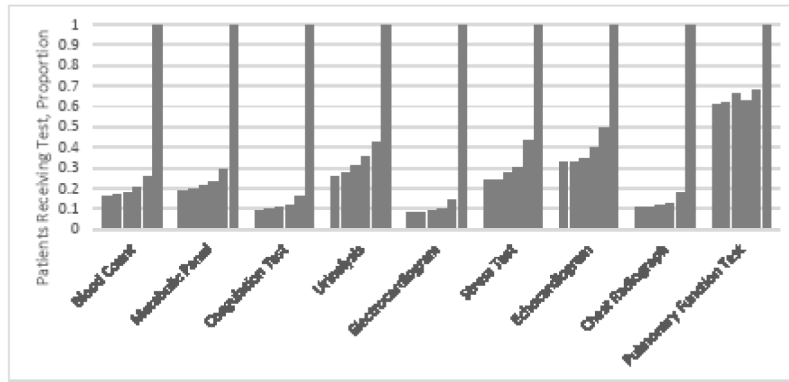
Figure 1.
Proportion of patients receiving each test during the six months prior to surgery. Proportions have been normalized so that the proportion receiving each test in preoperative month (the right-most column for each test) equals 1.

Table 1

Patient Characteristics

	Total	Lower-Risk Operations	Higher-Risk Operations
Patients	678,368	384,896 (56.3%)	293,472 (43.3%)
Age, median (IQR), y	51 (42–58)	51 (42–58)	51 (42–58)
Female Sex, N (%)	58.9	48.2	73.0
Comorbid Disease, %			
Hypertension	39.4	37.1	42.6
Hyperlipidemia	37.9	38.0	37.7
Diabetes	14.0	13.2	15.1
Chronic Pulmonary Disease	12.1	11.5	13.0
Anemia	9.8	7.2	13.3
Ischemic Heart Disease	6.1	5.8	6.5
Liver Disease	5.7	3.0	9.3
Cerebrovascular Disease	3.0	2.6	3.4
Venous Thromboembolism	1.7	1.6	1.8
Chronic Kidney Disease	1.6	1.4	1.8
Congestive Heart Failure	1.5	1.4	1.7
Atrial Fibrillation	1.5	1.5	1.7
Dementia	<0.1	<0.1	0.1
RCRI, %			
0	79.1	80.3	77.6
1	16.7	15.9	17.7
2	4.2	3.8	4.7
CCI, %			
0	62.7	68.0	55.8
1	22.5	21.2	24.1
2	14.9	10.8	20.1

Abbreviations: RCRI – Revised Cardiac Risk Index; CCI – Charlson Comorbidity Index; IQR – interquartile range

Table 2

Receipt of Preoperative Tests and Their Cost

	Blood Count	MP	Coag Test	UA	ECG	Stress Test	ECHO	CXR	PFT
Receipt of Test, %									
Cholecystectomy (n=132,536)	57.2	53.7	11.0	25.3	35.1	2.2	1.6	18.6	0.7
Hemorrhoidectomy (n=23,591)	24.4	21.4	5.2	9.4	15.8	0.9	0.7	7.3	0.5
CEA (n=2,671)	50.3	48.0	32.8	17.2	58.7	21.6	12.7	44.4	2.3
Peripheral artery angioplasty/stent (n=3,367)	51.5	48.4	36.8	11.7	28.9	4.3	3.1	17.2	1.3
Prostatectomy (n=16,393)	59.1	53.3	34.5	39.9	63.6	5.4	3.1	41.0	0.9
TURP (n=10,753)	49.6	48.3	19.7	55.6	45.3	2.6	2.0	19.6	1.2
Knee arthroplasty (n=71,524)	60.9	56.5	39.1	49.5	66.3	6.2	4.1	42.3	1.6
Arthroscopy (knee/shoulder) (n=326,595)	37.0	34.0	10.5	13.6	37.6	1.7	1.3	13.3	0.8
Hysterectomy (n=70,348)	60.0	37.9	12.9	29.1	34.1	1.6	1.4	20.4	0.8
Tubal ligation (n=20,590)	55.2	21.3	6.3	23.0	11.7	0.3	0.5	5.3	0.5
Total	46.8	40.6	14.5	22.8	39.0	2.4	1.7	18.6	0.9
Cost per patient, mean $									
Received test	28.85	50.02	31.85	13.60	66.62	932.65	533.51	85.72	72.38
All patients	13.51	20.33	4.62	3.09	26.00	22.22	9.16	15.92	0.62

Abbreviations: CEA –carotid endarterectomy; Coag – coagulation; CXR – chest radiograph; ECHO – echocardiograph; ECG – electrocardiogram; MP – metabolic panel; PFT – pulmonary function test; TURP – transurethral resection of the prostate

Table 3

Association of Patient- and Surgery-Specific Risk with Receipt of Preoperative Testing, Adjusted Analysis [a]

	Odds Ratio (95% CI)		
	RCRI = 1 [b]	RCRI 2 [b]	Higher-Risk Operations [c]
Blood Count	1.28 (1.22, 1.34)	1.47 (1.34, 1.62)	2.15 (1.46, 3.17)
Metabolic Panel	1.52 (1.43, 1.61)	1.70 (1.51, 1.93)	2.22 (1.50, 3.29)
Coagulation Test	1.29 (1.21, 1.39)	1.67 (1.42, 1.96)	3.82 (2.61, 5.61)
Urinalysis	1.23 (1.21, 1.27)	1.40 (1.30, 1.51)	3.53 (1.56, 7.99)
Electrocardiogram	1.37 (1.28, 1.47)	1.34 (1.20, 1.50)	2.33 (1.81, 3.01)
Stress Test	2.69 (2.46, 2.93)	4.96 (4.14, 5.94)	2.54 (2.28, 2.83)
Echocardiogram	2.44 (2.31, 2.59)	4.63 (4.19, 5.12)	2.23 (2.13, 2.34
Chest Radiograph	1.29 (1.24, 1.35)	1.49 (1.40, 1.58)	3.50 (3.35, 3.66)
Pulmonary Function Test	1.54 (1.47, 1.62)	2.30 (2.21, 2.40)	1.52 (1.27, 1.82)

Abbreviations: CI – confidence interval; CCI – Charlson Comorbidity Index

[a] Logistic regression models included RCRI score (0, 1, or 2), operation risk (higher-risk or lower-risk), and confounders (age, sex, and surgical specialty).

[b] reference group is RCRI = 0

[c] reference group is lower-risk operations

Appendix Table 1

Surgical procedures and their JHSCS Risk Category and CPT Codes

Surgery Type	JHSCS Risk Level [a]	CPT Codes
General Surgery		
Laparoscopic cholecystectomy [b]	2	47562–7564
Hemorrhoidectomy [b]	1 [c]	46083, 46221, 46250, 46255, 46260, 46320, 46500, 46930, 46945–46947
Vascular Surgery		
Carotid endarterectomy	4	35301
Peripheral artery angioplasty/stent [b]	2 [c]	37205, 37220, 37221, 37226, 37230, 37236
Urology		
Total Prostatectomy	4	55810, 55812, 55815, 55840, 55842, 55845, 55866
Transurethral resection of the prostate [b]	2 [c]	52450, 52601, 52612, 52614, 52630, 52647, 52648, 53850, 53852, 53853
Orthopedic Surgery		
Knee Arthroplasty	3	27445–27447, 27486, 27487
Arthroscopy (knee/shoulder) [b]	2	29806, 29807, 29819–29828, 29866–29868, 29870, 29871,29873–29877, 29879–29887
Gynecology		
Hysterectomy	3	58150; 58152; 58180, 58260, 58262, 58290, 58291, 58550, 58552–58554
Tubal Ligation [b]	2	58600, 58670, 58671

[a]The JHSCS risk category ranges from 1 (low risk) to 5 (high risk)

[b]include outpatient procedures only

[c]estimated

[d]Abbreviations: JHSCS – Johns Hopkins Surgical Classification System; CPT - Current Procedural Terminology

Appendix Table 2

Comorbidity diagnosis codes

Comorbidity	ICD-9-CM Codes
Diabetes	250
Ischemic Heart Disease	410–413, 414.0, 414.12, 414.2–414.9
Congestive Heart Failure	398.91, 402.01, 402.11, 402.91, 404.01, 404.03, 404.11, 404.13, 404.91, 404.93, 425.4–425.9, 428
Cerebrovascular Disease	362.34, 430–438
Chronic Kidney Disease	403.01, 403.11, 403.91, 404.02, 404.03, 404.12, 404.13, 404.92, 404.93, 582, 583.0–583.7, 585, 586, 588.0, V42.0, V45.1, V56
Chronic Pulmonary Disease	416.8, 416.9, 490–505, 506.4, 508.1, 508.8
Liver disease	070.22, 070.23, 070.32, 070.33, 070.44, 070.54, 070.6, 070.9, 456.0–456.2, 570, 571, 572.2–572.8, 573.3, 573.4, 573.8, 573.9, V42.7
Dementia	290, 294.1, 331.2
Hypertension	362.11, 401–405
Hyperlipidemia	272.0–272.4
Atrial Fibrillation	427.31
Anemia	280–285
Venous Thromboembolism	415.1, 416.2, 451–453

Abbreviations: ICD-9-CM, International Classification of Diseases, Ninth Revision, Clinical Modification

Appendix Table 3

Preoperative test CPT codes

Test group	Test	CPT code
Metabolic panel	Basic metabolic panel	80047, 80048
	Comprehensive metabolic panel	80053
	Renal function panel	80069
Blood count	Complete blood count	85025, 85027
	Hemoglobin	85018
	Hematocrit	85014
Coagulation test	PTT	85730
	PT w/INR	85610
Urinalysis	Urinalysis	81000, 81001, 81002, 81003, 81005
ECG	12-lead ECG	93000, 93005, 93010
Cardiac stress test	Stress ECG	93015, 93016, 93017, 93018
	Stress ECHO	93350, 93351
	Myocardial Perfusion Imaging	78451, 78452, 78453, 78454
	Stress MRI	75559, 75563
Echocardiography	Transthoracic Echocardiography	93303, 93304, 93306, 93307, 93308
Chest radiography	Chest radiograph	71010, 71020
PFT	Spirometry	94010
	Spirometry pre- and post-bronchodilator administration	94060
	Respiratory flow volume loop	94375

Abbreviations: CPT – Current Procedural Terminology; ECG – electrocardiogram; PFT – Pulmonary Function Testing; MRI – magnetic resonance imaging; PTT – partial thromboplastin time; PT – prothrombin time; INR – international normalized ratio

Appendix Table 4

Association of Patient- and Surgery-Specific Risk with Receipt of Preoperative Testing, Adjusted Analysis Using CCI as Measure of Patient-Specific Risk [a]

	Odds Ratio (95% CI)		
	CCI=1 [b]	CCI 2 [b]	Higher-Risk Operations [c]
Blood Count	1.27 (1.19, 1.35)	1.44 (1.27, 1.63)	2.11 (1.42, 3.12)
Metabolic Panel	1.39 (1.29, 1.50)	1.56 (1.31, 1.84)	2.17 (1.46, 3.21)
Coagulation Test	1.28 (1.25, 1.31)	1.54 (1.35, 1.76)	3.75 (2.44, 5.76)
Urinalysis	1.17 (1.11, 1.22)	1.11 (0.76, 1.62)	3.53 (1.58, 7.90)
Electrocardiogram	1.29 (1.26, 1.32)	1.33 (1.29, 1.38)	2.30 (1.81, 2.91)
Stress Test	1.70 (1.47, 1.97)	2.05 (1.72, 2.44)	2.59 (2.31, 2.90)
Echocardiogram	1.75 (1.59, 1.93)	2.56 (2.32, 2.81)	2.24 (1.96, 2.55)
Chest Radiograph	1.35 (1.30, 1.40)	1.51 (1.43, 1.59)	3.42 (3.13, 3.74)
Pulmonary Function Test	4.64 (4.37, 4.93)	6.33 (5.90, 6.80)	1.36 (1.01, 1.81)

Abbreviations: CI – confidence interval; CCI – Charlson Comorbidity Index

[a] Logistic regression models included CCI score (0, 1, or 2), operation risk (higher-risk or lower-risk), and confounders (age, sex, and surgical specialty).

[b] reference group is CCI = 0

[c] reference group is lower-risk operations

Appendix Table 5

Association of Patient- and Surgery-Specific Risk with Receipt of Preoperative Testing, Adjusted Analysis including non-RCRI Comorbidities [a]

	Odds Ratio (95% CI)		
	RCRI=1 [b]	**RCRI ≥ 2** [b]	**Higher-Risk Operations** [c]
Blood Count	1.14 (1.11, 1.16)	1.19 (1.09, 1.28)	2.09 (1.42, 3.10)
Metabolic Panel	1.28 (1.24, 1.32)	1.29 (1.18, 1.40)	2.14 (1.43, 3.21)
Coagulation Test	1.14 (1.08, 1.21)	1.26 (1.09, 1.44)	3.76 (2.60, 5.44)
Urinalysis	1.14 (1.10, 1.18)	1.21 (1.11, 1.32)	3.47 (1.55, 7.79)
Electrocardiogram	1.16 (1.10, 1.22)	1.02 (0.94, 1.11)	2.26 (1.73, 2.94)
Stress Test	2.27 (2.09, 2.48)	3.88 (3.31, 4.55)	2.48 (2.19, 2.80)
Echocardiogram	2.02 (1.92, 2.12)	3.28 (3.06, 3.51)	2.13 (1.99, 2.29)
Chest Radiograph	1.15 (1.11, 1.20)	1.22 (1.15, 1.28)	3.42 (3.31, 3.54)
Pulmonary Function Test	1.22 (1.18, 1.25)	1.32 (1.20, 1.44)	1.47 (1.28, 1.68)

Abbreviations: CI – confidence interval; RCRI – Revised Cardiac Risk Index

[a] Logistic regression models included RCRI score (0, 1, or ≥ 2), operation risk (higher-risk or lower-risk), non-RCRI comorbidities (hypertension, hyperlipidemia, liver disease, thromboembolism, chronic pulmonary disease, atrial fibrillation, anemia, and dementia) and confounders (age, sex, surgical specialty).

[b] reference group is RCRI = 0

[c] reference group is lower-risk operations

Appendix Table 6

Association of Patient- and Surgery-Specific Risk with Receipt of Preoperative Testing, Adjusted Analysis including an Interaction Term Between Patient- and Surgery-Specific Risk Variables, Stratified by Patient-Specific Risk[a]

	Odds Ratio (95% CI)		
	RCRI=0	**RCRI=1**	**RCRI 2**
	Higher-Risk Operations [b]	**Higher-Risk Operations** [b]	**Higher-Risk Operations** [b]
Blood Count	2.35 (1.55, 3.56)	1.69 (1.21, 2.36)	1.47 (1.13, 1.93)
Metabolic Panel	2.51 (1.72, 3.66)	1.62 (1.12, 2.35)	1.34 (0.99, 1.82)
Coagulation Test	4.13 (2.67, 6.40)	3.44 (2.55, 4.65)	2.68 (1.76, 4.08)
Urinalysis	3.79 (1.60, 9.00)	3.03 (1.39, 6.62)	2.54 (1.27, 5.11)
Electrocardiogram	2.47 (2.07, 2.95)	2.05 (1.34, 3.14)	1.84 (1.00, 3.39)
Stress Test	2.91 (2.70, 3.14)	2.38 (2.06, 2.75)	2.07 (1.43, 2.99)
Echocardiogram	2.49 (2.17, 2.87)	2.09 (1.89, 2.31)	1.88 (1.44, 2.45)
Chest Radiograph	3.72 (3.34, 4.13)	3.12 (2.91, 3.36)	2.80 (2.31, 3.39)
Pulmonary Function Test	1.59 (1.27, 2.00)	1.42 (1.21, 1.68)	1.38 (1.20, 1.58)

Abbreviations: CI – confidence interval; RCRI – Revised Cardiac Risk Index

[a]Logistic regression models included RCRI score (0, 1, or 2), operation risk (higher-risk or lower-risk), an interaction term between RCRI and operation risk, and confounders (age, sex, surgical specialty).

[b]reference group is lower-risk operations

Appendix Table 7

Association of Patient- and Surgery-Specific Risk with Receipt of Preoperative Testing, Adjusted Analysis including an Interaction Term Between Patient- and Surgery-Specific Risk Variables, Stratified by Surgery-Specific Risk [a]

	Odds Ratio (95% CI)			
	Lower-Risk Operations		Higher-Risk Operations	
	RCRI=1 [b]	RCRI 2 [b]	RCRI=1 [b]	RCRI 2 [b]
Blood Count	1.48 (1.36, 1.61)	1.82 (1.60, 2.06)	1.07 (0.92, 1.24)	1.14 (0.92, 1.41)
Metabolic Panel	1.85 (1.67, 2.04)	2.27 (1.97, 2.62)	1.19 (0.97, 1.47)	1.21 (1.00, 1.47)
Coagulation Test	1.43 (1.37, 1.49)	2.11 (2.01, 2.22)	1.19 (0.96, 1.47)	1.37 (0.89, 2.11)
Urinalysis	1.40 (1.24, 1.57)	1.75 (1.50, 2.03)	1.12 (0.97, 1.28)	1.17 (0.92, 1.48)
Electrocardiogram	1.49 (1.43, 1.54)	1.53 (1.39, 1.69)	1.23 (0.92, 1.66)	1.14 (0.73, 1.77)
Stress Test	3.03 (2.80, 3.27)	6.09 (4.40, 8.42)	2.48 (2.17, 2.83)	4.32 (3.86, 4.85)
Echocardiogram	2.70 (2.61, 2.80)	5.47 (4.67, 6.40)	2.27 (1.87, 2.75)	4.11 (3.06, 5.52)
Chest Radiograph	1.42 (1.39, 1.45)	1.74 (1.62, 1.86)	1.19 (1.01, 1.41)	1.31 (1.02, 1.69)
Pulmonary Function Test	1.63 (1.54, 1.72)	2.48 (2.36, 2.60)	1.46 (1.24, 1.71)	2.15 (1.90, 2.42)

Abbreviations: CI – confidence interval; RCRI – Revised Cardiac Risk Index

[a] Logistic regression models included RCRI score (0, 1, or 2), operation risk (higher-risk or lower-risk), an interaction term between RCRI and operation risk, and confounders (age, sex, surgical specialty).

[b] reference group is RCRI=0