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Reduced Preoperative Testing is not Associated with Inferior Outcomes after Orthopedic Surgery

*Caitlyn Tang[1], Jordan Starr[2], Howard A. Chansky[3] and Irene Rozet[1,2]**

[1]Department of Anesthesiology, Veterans Affairs, Puget Sound Health Care System, Seattle, WA 98015, USA

[2]Department of Anesthesiology and Pain Medicine, University of Washington, Seattle, WA, USA

[3]Department of Orthopedics and Sport Medicine, University of Washington, Seattle, WA, USA

Abstract

Purpose: Routine preoperative testing is not recommended in patients with mild comorbidities. We hypothesized that routine testing can be safely reduced in patients with multiple comorbidities undergoing orthopedic surgery.

Methods: To evaluate noninferiority and cost-effectiveness of the preoperative patient and surgery-specific protocol of reduced testing (RT), patients' demographics, comorbidities, and preoperative tests ordered prior to surgery were retrospectively gathered and compared between the RT (April 2012 - November 2013) and the historic testing (HT) periods (July 2010 – March 2012). Length of stay (LOS), in-hospital, 30-day, and one-year mortality were primary outcomes. The cost was a secondary outcome. For each outcome, separate propensity matched cohorts were created. Differences between the cohorts were evaluated with a non-inferiority analysis.

Results: The study included 2,263 patients: 91.5% males, a mean age 58.2 (SD 13.1) years, 62.9% ASA III-IV. There was no difference in LOS (CI -0.5 – 1.0, p = 0.065), in-hospital (OR 1.00, CI 0.12 – 8.35, p = 0.991), 30-day (OR 1.76, CI 0.53 – 6.72, p = 1.000), or 1-year mortality (OR 1.52, CI0.90 – 2.59, p = 1.000) between RT (n=1,091) and HT (n=1,172). The number of tests in the RT was lower than in the HT (1.5 vs. 2.9 tests/case, p < 0.001) and cost $33 less per case.

Conclusions: Our patient and surgery-specific protocol for preoperative testing before orthopedic surgery was not associated with inferior outcomes, but reduced numbers of tests and cost, compared to a historic control.

Keywords: Preoperative; Tests; Cost; Outcome; Orthopedic surgery

Abbreviations

PAC: Pre-Anesthesia Clinic; CXR: Chest Radiograph; ECG: Electrocardiogram; RT: Reduced Testing; HT: Historic Testing; VINCI: Veterans Affairs Informatics and Computing Infrastructure (sex, age, LOS); LOS: Length of Stay; BMP: Basic Metabolic Panel (serum sodium, potassium, chloride, bicarbonate, blood urea nitrogen, creatinine, and glucose); CBC: Complete Blood Count (hemoglobin, hematocrit, platelet count, and white blood cell count).

Introduction

Despite the substantial cost associated with preoperative testing, which is estimated between $3 billion to $18 billion annually in the United States [1-3], its indications and effectiveness have been questioned [2-5]. The Choosing Wisely campaign recommends against obtaining baseline preoperative laboratory studies in patients without significant systemic disease undergoing low risk surgery [4].

Two decades ago, routine preoperative laboratory testing was shown neither to change perioperative management, nor to affect the incidence of perioperative adverse events in healthy patients undergoing elective, non-cardiac surgeries [5-10]. Recent studies support similar recommendations for elderly patients with comorbidities undergoing minor surgery, such as patients undergoing cataract repair [1,10-11]. Patients undergoing cataract surgery showed no difference in postoperative adverse events whether or not they received any preoperative laboratory testing [10-14]. In addition to laboratory testing, abnormal chest radiographs (CXRs) and electrocardiograms (ECGs) only result in changes to perioperative management less than 5% of the time [15-22] and are

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*Correspondence:
Irene Rozet, Department of Anesthesiology, Veterans Affairs, Puget Sound Health Care System, Seattle, Department of Anesthesiology and Pain Medicine, University of Washington, ANES - 112, 1660 S Columbian Way, Seattle, WA, 98015, USA.
Tel: 206-764-2117l
Fax: 206-764-2914
E-mail: irozet@uw.edu

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Table 1: Reduced Testing Protocol.

Test	Indications
CBC	Surgery Specific
	Joint replacement surgery
	Patient – Specific
	Known hematologic disorder
	Recent chemotherapy (in previous 6 months)
BMP	Significant liver or renal disease
	Chronic treatment with diuretics
Albumin	Patients with predisposing factors for malnutrition only
Coagulation	History of coagulopathy
(PT, PTT, INR)	Warfarin or heparin therapy
HbA1C	Patients with diabetes, if not done or abnormal in the past 3 months
LFTs	Liver disease
ECG	Age >50 y or clinically indicated*
CXR	Suspected acute pulmonary disease only

CBC: Complete Blood Count; BMP: Basic Metabolic Panel (serum sodium, potassium, chloride, bicarbonate, blood urea nitrogen, creatinine, and glucose); HgbA1C: Hemoglobin A1C; LFTs: Liver Function Tests; ECGs: Electrocardiograms; CXR: Chest Radiographs; PT: Prothrombin Time; PTT: Partial Prothrombin Time; INR: International Ratio.

*- suspected Ischemic Heart Disease (new onset or change of clinical signs as shortness of breath or chest pain), known implanted cardiac devices, known or suspected arrhythmia lightheadedness, palpitations, or syncope).

not recommended routinely [4, 23].

Despite evidence that routine non-specific preoperative testing is not advantageous, it continues to be commonly utilized [24]. At least half of practitioners, especially non-anesthesiologists involved in the preoperative assessment of surgical patients are not compliant with common recommendations [24-25].

At our institution, a regional 400 bed Veteran Affairs Medical Center, the patient population is predominantly male with a high prevalence of comorbid conditions. Surgical services provided in our hospital include general surgery, urology, orthopedics, vascular, neurosurgery, plastics, otorhinolaryngology, podiatry, cardiac, thoracic, ophthalmology, and gynecology surgery. Historically, there was no established preoperative testing protocol, and a battery of tests was routinely ordered by surgical providers and/or internal medicine consultants, and/or other providers involved in patient's preoperative care. Following establishment of the Pre-Anesthesia Clinic (PAC) led by the Anesthesiology Department, we developed a patient- and surgery-specific "reduced" testing protocol (RT) to limit unnecessary preoperative testing, which was managed by the PAC staff. The protocol was guided by relevant clinical guidelines regarding preoperative testing, clinical characteristics of the VA patient population, and by collaboration with representatives of the section of Orthopaedic Surgery (Table 1). The protocol was implemented in March 2012.

In this study, we hypothesized that implementation of the RT protocol was safe and cost effective in patients with various comorbidities undergoing all spectra of orthopaedic surgeries. The aim of the study was to investigate if a change of practice from the "historical" way of ordering preoperative tests (HT) to the novel RT protocol would affect outcomes in patients undergoing orthopaedic surgery.

Materials and Methods

Study design and setting

After VA IRB approval with a waiver of informed consent, this retrospective cohort study was conducted at the Veteran Affairs Medical Center, a tertiary-care and referral center for patients from Washington, Alaska, Idaho, and parts of Oregon. All patients undergoing elective or urgent surgery undergo a preoperative evaluation in person within 14 days prior to surgery in the PAC. The PAC team includes three nurse practitioners, one physician assistant, one anesthesia resident, and an attending anesthesiologist overseeing all the patients with significant comorbidities (ASA III-IV), patients scheduled for major surgeries, and consulting all the patients requiring additional preoperative interventions.

Historically, preoperative tests were ordered by the surgical service or a consultant internist and included obtaining a basic metabolic panel (BMP) (serum sodium, potassium, chloride, bicarbonate, blood urea nitrogen, creatinine, and glucose), serum albumin level, a complete blood count (CBC), a coagulation panel (PT/INR and PTT), an ECG in all patients older than 40 years, and a chest radiograph (CXR). The choice of tests also varied somewhat by ordering provider. In March 2012, the PAC implemented a new protocol to reduce unnecessary preoperative testing ("RT" protocol) (Table 1). The tests were individually ordered by providers in the PAC in accordance with the new protocol.

Patients who underwent elective and urgent orthopedic surgery from July 1, 2010 to November 30, 2013 and were evaluated in the PAC prior to surgery were included into the cohort and formed 2 groups: a historical testing (HT) group (July 1, 2010- February 29, 2012) and a reduced testing group (RT) (March 1, 2012 – November 30, 2013).

Measurement and data collection

The pertinent data were abstracted through the VA Informatics and Computing Infrastructure (VINCI) database. Sex, age, surgical procedure, preoperative tests, length of stay (LOS), postoperative mortality, and major comorbidities were abstracted from the database. The analysis of preoperative tests was limited to the most relevant and commonly ordered ones: ECG, CXR, CBC, BMP, serum albumin, liver function tests (LFTs), coagulation panel, and hemoglobin A1c (HbA1c) obtained within 14 days prior to surgery.

The relevant perioperative clinical risk predictors were collected and included American Society of Anesthesiologists (ASA) class and the Revised Cardiac Risk Index (RCRI) [26] predictors retrieved by 2012 ICD -9-CM Codes: 1) ischemic heart disease (IHD) (2012 ICD-9-CM Codes 410-414), 2) congestive heart failure (CHF) (2012 ICD-9-CM Codes 425, 428), 3) cerebrovascular disease (CVD) (2012 ICD-9-CM 430-438), 4) diabetes mellitus (DM) (2012 ICD-9-CM Code 250), and 5) chronic kidney disease (CKD) (2012 ICD-9-CM Codes 585, 586). Post-operative mortality was assessed in-hospital, at 30-days, and at one-year.

Costs of tests were calculated based on the reimbursement rates from the Centers for Medicare and Medicaid Services provided by the facility's laboratory and cost recovery departments.

Statistical analyses

All statistical analyses were performed using PASW 21 and R (The R Foundation for Statistical Computing, Vienna, Austria) [27]. Descriptive statistics were performed to summarize the population

Table 2: Baseline Characteristics of Study Groups.

	Total (n = 2,263)	Historical (HT) (n = 1,172)	Reduced (RT) (n = 1,091)	P-value*
Age, mean (sd)	58.2 (13.1)	57.5 (13.6)	58.9 (12.5)	0.010
Male (%)	2,071 (91.5)	1,076 (91.8)	995 (91.2)	0.604
ASA Class, n (%)				0.040
I	100 (4.4)	64 (5.5)	36 (3.3)	
II	738 (32.6)	398 (34.0)	340 (31.2)	
III	1,248 (55.1)	612 (52.2)	636 (58.3)	
IV	177 (7.8)	98 (8.4)	79 (7.2)	
CHF, n (%)	13 (0.6)	5 (0.4)	8 (0.7)	0.335
CKD, n (%)	79 (3.5)	35 (3.0)	44 (4.0)	0.175
CVD, n (%)	28 (1.2)	13 (1.1)	15 (1.4)	0.568
IDDM, n (%)	433 (19.1)	207 (17.7)	226 (20.7)	0.065
IHD, n (%)	104 (4.6)	35 (3.0)	69 (6.3)	< 0.001
Outpatient, n (%)	916 (40.5)	484 (41.3)	432 (39.6)	0.410
Procedure, n (%)				0.056
Arthroscopic	322 (14.2)	185 (15.8)	137 (12.6)	
Fracture Repair	240 (10.6)	127 (10.8)	113 (10.4)	
Hand, Wrist, Finger	184 (8.1)	113 (9.6)	71 (6.5)	
Implant Removal	191 (8.4)	92 (7.9)	99 (9.1)	
Incision & Drainage	111 (4.9)	52 (4.4)	59 (5.4)	
Lower Extremity Amputation	102 (4.5)	54 (4.6)	48 (4.4)	
Other	219 (9.7)	111 (9.5)	108 (9.9)	
Total Hip Replacement	329 (14.5)	164 (14.0)	165 (15.1)	
Total Knee Replacement	499 (22.1)	244 (20.8)	255 (23.4)	
Shoulder Replacement	66 (2.9)	30 (2.6)	36 (3.3)	
High-risk procedure**	453 (20.0)	233 (19.9)	220 (20.2)	0.866

ASA: American Society of Anesthesiologists class; IHD: Ischemic Heart Disease; CHF: Congestive Heart Failure; CVD: Cerebrovascular Disease (CVD); DM: Diabetes Mellitus; CKD: Chronic Kidney Disease;

*P-values obtained with Pearson's Chi-squared tests, except for age (Student's t-test) and ASA class (Kruskal- Wallis rank sum test).

**High-risk procedures defined as those with a 30-day mortality rate higher than the average 30-day mortality rate in this study. These included fracture repairs, incision and drainages, and lower extremity amputations.

overall and the cohort for each testing period. Univariate testing to compare the two testing periods was performed with Pearson's Chi-squared test, Student's t-test, and the Kruskal-Wallis rank sum test as appropriate. Pearson's Chi-squared or Fisher's exact test were also used to test the significance of differences in the numbers of preoperative tests between the two periods.

Prior to propensity matching, a crude analysis was performed to test for non-inferiority of the ST protocol vs. the RT protocol for each of the outcomes of interest. Non-inferiority for length of stay was tested using the methods described in Mascha et al [28]. Non-inferiority testing for the three mortality-related outcomes was performed with the R package gs Design by a Chi-square statistic that compares two binomial event rates using the method of Miettinen et al [29,30].

To perform the adjusted analysis, propensity matching was employed to create separately matched cohorts for each outcome of interest. Covariates included for propensity matching were all those significantly associated with either testing period or the respective outcome of interest, as described in Austin et al [31]. Covariates were tested for univariate associations with the outcomes of interest using the Wilcoxon rank sum test (length of stay) or Fisher's exact test (all three mortality outcomes). Significance was defined as a p-value < 0.05. All models were created with the nearest neighbor method, a 1:1 matching ratio, and a caliper distance of 0.1. All models were ensured, for all covariates, to have standardized mean differences between -0.1 – 0.1 and variance ratios between 0.5 – 2 (Appendix) [30]. After propensity matching, non-inferiority analyses for each outcome were repeated. For length of stay, a paired T-test for non-inferiority was employed. For the three mortality related outcomes, a paired non-inferiority test was utilized as described by Nam [32].

Finally, a post-hoc power analysis was performed for each primary outcome assuming an alpha of 0.05 and a beta of 0.2. For length of stay, the methods in Mascha et al. were again utilized [28]. For the three mortality related outcomes, the R package gs Design was used incorporating methods described in Farrington et al [33]. The purpose of this post- hoc power analysis was to illustrate the limits of the sensitivity of this study.

Results

Cohort characteristics and propensity matching

During the study period, a total of 2,722 cases of nonemergency, elective or urgent orthopedic surgery were identified. After excluding cases with missing data, the study sample comprised a total of 2,263 cases: 1,172 in the HT group and 1,091 in the RT group. Baseline characteristics of patients in study groups are presented in Table 2. The mean age of the study population (91.5% male) was 58.2 (SD 13.1 years, range 21-91 years); 62.9% of patients were ASA class III - IV. Patients in the RT group tended to be older, have higher ASA classes, and had a higher rate of IHD (Table 2). Because age, ASA class, and IHD were all associated with the RT period, these covariates were included in all four propensity matching models.

Surgical procedures were categorized into average vs. high-risk. High-risk procedures were defined as those with a 30-day mortality higher than the average 30-day mortality. These included fracture repairs, incision and drainages, and lower extremity amputations (Table 2).

By univariate analysis, length of stay was associated with sex, CHF, CKD, CVD, DM, and high-risk surgery, so these covariates were included in its propensity score model. In-hospital mortality was associated with CKD and high-risk surgery, and were thus included in its propensity score model. 30-day mortality was associated with high- risk surgery, so this covariate was included in its model. Lastly, 1-year mortality was associated with CHF, CKD, CVD, DM, and high-risk surgery, so these covariates were included in its model. Because a caliper distance was incorporated for matching, not all patients could be successfully matched. Out of 2,263 total patients, the length of stay model matched 2,086 patients; the in-hospital mortality model matched 2,094 patients; the 30-day mortality model matched 2,102 patients; and the 1-year mortality model matched 2,094 patients.

Outcomes

Prior to adjustment, the RT group was not associated with inferior length of stay (difference 0.6 days, CI -0.3 – 1.4, p = 0.189), in-hospital mortality (OR 1.07, CI 0.13-8.97, p = 0.992), 30- day mortality (OR 1.89, CI 0.57 – 7.22, p = 0.990), or 1-year mortality (OR 1.55, CI 0.97 – 2.49, p = 0.994). After propensity matching, the RT group remained

Table 3: Unadjusted non-inferiority analysis.

	Total (median, IQR)	Historical (HT) (median, IQR)	Reduced (RT) (median, IQR)	Mean Difference (95% CI)	P-value
Length of Stay	14 (1 – 26)	11 (1 – 26)	14 (1 – 26)	0.6 (-0.3 – 1.4)	0.189
	Total (n, %)	Historical (n, %)	Novel (n, %)	OR (95% CI)	P-value
In-hospital mortality	4 (0.2)	2 (0.2)	2 (0.2)	1.07 (0.13 – 8.97)	0.992
30-day mortality	11 (0.5)	4 (0.3)	7 (0.6)	1.89 (0.57 – 7.22)	0.990
1-year mortality	75 (3.3)	31 (2.6)	44 (4.0)	1.55 (0.97 – 2.49)	0.994

Table 4: Propensity-matched non-inferiority analysis.

	Total (median, IQR)	Historical (HT) (median, IQR)	Reduced (RT) (median, IQR)	Mean Difference (95% CI)	P-value
Length of Stay	14 (1 - 26)	14 (1 – 26)	14 (1 – 26)	0.3 (-0.5 - 1)	0.0653
	Total (n, %)	Historical (n, %)	Novel (n, %)	OR (95% CI)	P-value
In-hospital mortality	4 (0.2)	2 (0.2)	2 (0.2)	1.00 (0.12 – 8.35)	0.9912
30-day mortality	11 (0.5)	4 (0.4)	7 (0.7)	1.76 (0.53 – 6.72)	0.9997
1-year mortality	60 (2.9)	24 (2.3)	36 (3.4)	1.52 (0.90 – 2.59)	1.000

unassociated with inferior length of stay (difference 0.3 days, CI -0.5 – 1.0, p = 0.065), in-hospital mortality (OR 1.00, CI 0.12 - 8.35, p = 0.991), 30-day mortality (OR 1.76, CI 0.53 – 6.72, p = 1.000), or 1-year mortality (OR 1.52, CI 0.90 – 2.59, p = 1.000). These results are further characterized in Tables 3 and 4.

Preoperative tests

Application of the RT protocol resulted in ordering CBC in 26%, BMP in 17%, PT/PTT in 11%, Albumin in 12%, HbA1C in 0.7%, ECG in 80%, and CXR in 0.1% of patients (Figure 1).

Compared to historic testing, introduction of the RT protocol caused a relative reduction in ordered tests by 60% for CBC, 68% for BMP, 67% for PT/PTT, 73% for Albumin, 73% for LFTs, 96% for CXR, and by 10% for ECG. The RT period had significantly fewer pre-operative tests compared with the HT: 0.7 versus 2.03 laboratory tests per case, and 1.5 versus 2.9 total tests per case when including CXR and ECG (Figure 1). However, testing for HbA1c increased by 30%.

Based on the reimbursement rates adapted by Medicare, the RT period resulted in a savings of $3.97 per procedure for CBC; $3.97 per procedure for BMP; $2.23 per procedure for albumin; $3.13 per procedure for coagulation tests; and $0.10 per procedure for LFTs (Table 5). Two additional HbA1Cs conducted in the RT group resulted in a total cost increase of $26.5. There were 29 CXRs ordered and completed in the HT group and only one in the RT group, which resulted in a savings of $9.86 per procedure. The savings with reduction of ordering ECGs resulted in $9.72 per procedure. When all the laboratory tests and studies were averaged on a per procedure basis, the average cost per procedure was $127.23 in the HT group and $94.27 in the RT group. This represents a savings of $32.96 per procedure during the RT period.

Post-hoc power analysis

By post-hoc analysis, this study was powered to detect a 0.9-day difference in length of stay, which was rounded to 1 day for the purpose of our analysis. In-hospital mortality was powered to detect a difference as small as a 0.7% absolute increase. 30-day mortality was powered to detect a difference as small as a 1.2% absolute increase. Lastly, 1-year mortality was powered to detect a difference as small as a 3.4% absolute increase.

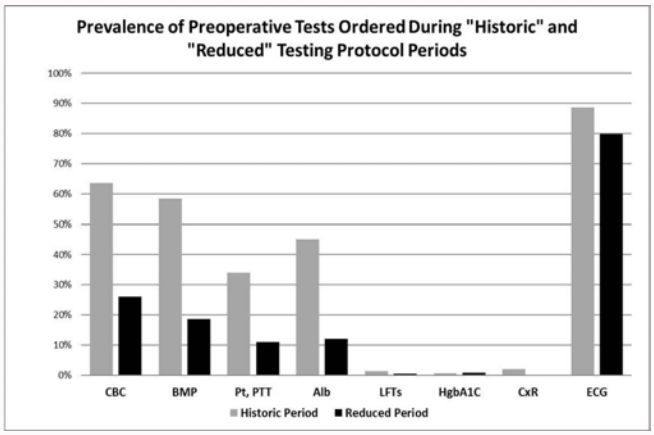

Figure 1: Prevalence of Test Ordering in Historic and Reduced Testing Periods.
Axis Y represents 100% of cases in the Historic or Reduced study period. CBC- complete blood count, BMP -basic metabolic panel (serum sodium, potassium, chloride, bicarbonate, blood urea nitrogen, and creatinine), Alb-serum albumin level, PT/PTT - a coagulation panel (PT/INR and PTT), LFTs – liver function tests, ECG – electrocardiography, CxR - a chest radiograph. In HT group, CBC were ordered in 64%, BMP -in 58%, PT/PTT -in 34%, Albumin in 45%, LFTs in 1.5%, CxR in 2% and ECG in 89% of cases. In RT group, CBC were ordered in CBC in 26%, BMP in 17%, PT/PTT in 11%, Albumin in 12%, Hgb A1C in 0.7%, ECG in 80%, and CXR in 0.1% of patients.

Discussion

Preoperative studies and laboratory tests account for a significant portion in health care costs annually. Over the past three decades, a substantial body of research has raised questions on the predictive value of routine testing before surgery as laboratory abnormalities seldom lead to changes in the perioperative management, and moreover, can lead to further unnecessary testing and even to morbidity [5-16].

To our knowledge, this study is novel in multiple aspects: 1) this is the first study evaluating the effects of preoperative testing on surgical outcomes in a specific patients patient's population with moderate and severe systemic diseases undergoing intermediate and high-risk orthopedic surgery; 2) this is the first study evaluating a possible effect of the preoperative testing in nonambulatory surgeries on the long-term (one-year) postoperative outcomes, and 3) this is also the first study utilizing an appropriate statistical methodology by applying propensity matching, which is absent in the existing literature. The findings of this study demonstrate that our protocol of reduced

Table 5: Preoperative Tests and Costs.

Test (Price)	Historical Testing (HT)			Reduced Testing (RT)					
	Cost (N of tests X price)	Prevalence of Test (N of tests÷ N of surgeries)	Cost per Surgery (Total price÷ N of surgeries)	Cost (N of tests X price)	Prevalence of Test (N of tests÷ N of surgeries)	Cost of testing per Surgery (Total price÷ N of surgeries)	Difference between HT and RT*	Savings	Saving per surgery
CBC ($10.61)	880 x$10.61 = $9,336.80	64%	$9,336.80 ÷ 1385= $6.74	349 x $10.61 = $3,702.89	26%	$3,702.89 ÷1337= $2.77	-59%	$5,633.91	$3.97
Chem 7 ($10.00)	809 x $10 = $8,090	58%	$8,090 ÷ 1385= $5.84	250x $10 = $2,500	17%	$2,500 ÷ 1337 = $1.87	-68%	$5,590	$3.97
Anticoag ($13.56)	472 x$13.56 = $6,400.32	34%	$6,400.32 ÷ 1385= $4.62	147 x $13.56 = $1,993.32	11%	$1,993.32 ÷ 1337 = $1.49	-67%	$4,407	$3.13
Albumin ($6.75)	624 x $6.75 = $4,212	45%	$4,212 ÷ 1385= $3.04	160 x $6.75 = $1,080	12%	$1,080 ÷ 1337 = $0.81	-73%	$3,132	$2.23
LFTs ($8.62)	19x$8.62 = $163.78	1.40%	$163.78 ÷ 1385= $0.12	5x$8.62 = $43.10	0.30%	$43.10 ÷ 1337 = $0.03	-73%	$120.68	$0.09
Hemoglobin A1c ($13.24)	8 x $13.24 =$105.92	0.50%	$105.92 ÷ 1385= $0.08	10 x $13.24 =$132.40	0.70%	132.40÷ 1337 = $0.10	29%	($26.48)	($0.02)
CXR ($488.69)	29 x $488.69 = $14,172.01	2%	$14,172.01 ÷ 1385= $10.23	1x $488.69 = $488.69	0.10%	$488.69 ÷ 1337 = $0.37	-96%	$13,683.302	$9.86
ECG ($108.81)	1229 x $108.81 = $133,727.49	89%	$133,727.49 ÷ 1385= $96.56	1067 x$108.81 = $116,100.27	80%	$116,100.27 ÷ 1337 = $86.84	-10%	$17,627.202	$9.72
Total	$176,208.32		$127.23	$126,040.67		$94.27		$50,141.1 7	$32.96

Difference between HT and RT : Difference of ordered tests between Historical and Reduced groups was calculated as a difference in proportion of test ordered in the Historic group and a proportion of tests ordered in the Reduced testing, relative to the Historic group.

patient and surgery-specific testing is not inferior to routine practice in a population with significant comorbidities as it did not worsen length of stay or short (1 month), or long term (1 year) postoperative mortality. Furthermore, it reduced cost.

The majority of our patients were ASA III-IV, and older than 60 years. Over 20% underwent high-risk surgeries. With our protocol, only 26% of patients in the cohort required preoperative CBC and even fewer required a BMP or coagulation panel, the most commonly ordered laboratory tests. Our data supports reduced protocol-based preoperative testing that is tailored to the patient and his/her procedure.

Moreover, abnormalities in preoperative tests usually do not alter the surgical plan, as surgery would be performed regardless of abnormal results in about 60% of patients [6-9]. In fact, a systematic review conducted by Smetana and Macpherson [26] found that only 0.2% to 2.6% of laboratory abnormalities detected on preoperative testing changed perioperative management and no surgical cases were being canceled due to the abnormal results.

Whether our protocol may be considered as one that only recommends "indicated" testing is arguable. Although our protocol in general in concurred with the most recently published recommendations for preoperative testing [34], it was still rather conservative. For example, by the RT protocol, all patients older than 50 years received an ECG. Nevertheless, we still reduced ordering of the most common tests by 60-70% in comparison to the historical practice. This is consistent with a previous investigation showing a 55% reduction in the number of preoperative tests after ordering of preoperative tests was changed from surgeons to a dedicated PAC [22]. A previous survey showed that approximately 67% of preoperative tests ordered by surgeons are not clinically indicated [27].

In our institution, the economic implications of transferring preoperative testing to the preexisting PAC team was substantial. Whether creation of the new PAC team is profitable in the short or long- term, however, is certainly institution-dependent.

There were several limitations to our study. Our study was retrospective and, as we examined data extracted from the VINCI database, our results depend on the accuracy of data abstraction from the medical record. In particular, our results are dependent upon the accuracy of ICD-9 coding. There was an inevitable component of missing data, requiring exclusion of these cases. Finally, the total amount of preoperative tests in the HT period might be underestimated as we limited our search to 14 preoperative days. This would not be a factor in the RT group, where the tests were retrieved by the individual PAC provider's name. Therefore, if there was an error in the number of tests in the HT group, it would be underestimated, not overestimated, leading to even more dramatic differences between groups.

In summary, despite the high burden of comorbidities in our population, our data suggest that our protocol-driven preoperative testing in orthopedic patients undergoing broad spectra of surgeries was not inferior to routine inclusive preoperative testing in regard to length-of-stay and mortality. In our institution, implementation of the protocol also led to decreased cost. The savings, however, may significantly vary across institutions. As we retrospectively examined selected group of patients undergoing orthopedic surgeries only,

further prospective studies would be helpful to evaluate the effects of similar protocols in other surgical populations.

Conclusion

Our data suggest that patient and surgery-specific protocol-driven preoperative testing may be safe and cost effective in patients with multiple comorbidities undergoing broad spectra of orthopedic surgeries.

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