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Are perioperative bundles associated with reduced postoperative morbidity in women undergoing benign hysterectomy? Retrospective cohort analysis of 16,286 cases in Michigan

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Abstract

Background—Healthcare teams that frequently follow a bundle of evidence-based processes provide care with lower rates of morbidity. Few process bundles to improve surgical outcomes in hysterectomy have been identified.

Objectives—To investigate if a bundle of four perioperative care processes is associated with fewer postoperative complications and readmissions for hysterectomies in the Michigan Surgical Quality Collaborative (MSQC).

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Study Design—A bundle of perioperative care process goals was developed retrospectively with 30 day peri- and post-operative outcome data from the Hysterectomy Initiative in MSQC. All benign hysterectomies performed between January 2013 and January 2015 were included. Based on evidence of lower complication rates after benign hysterectomy, the following processes were considered the “bundle”—use of guideline-appropriate preoperative antibiotics, a minimally invasive surgical approach, operative duration less than 120 minutes, and avoidance of intraoperative hemostatic agent use. Each process was considered present or absent and the number of processes was summed for a bundle score ranging from zero to four. Cases with a score of zero were excluded. Outcomes measured were rates of complications (any and major) and hospital readmissions, all within 30 days of surgery. Postoperative events considered a “major complication” included acute renal failure, cardiac arrest requiring cardiopulmonary resuscitation, central line infection, cerebral vascular accident, death, deep vein thrombosis, intestinal obstruction, myocardial infarction, pelvic abscess, pulmonary embolism, rectovaginal fistula, sepsis, surgical site infection (deep and organ-space), unplanned intubation, ureteral obstruction, ureterovaginal and vesicovaginal fistula. The outcome “any complication” included all those events already described in addition to blood transfusion within 72 hours of surgery, urinary tract infection, and superficial surgical site infection. Outcomes were adjusted for patient demographics, surgical factors, and hospital-level clustering effects.

Results—16,286 benign hysterectomies were available for analysis. Among all hysterectomies reviewed, 33.6% met criteria for all bundle processes; however, there was wide variation in the rate among the 56 hospitals in the study sample with 9.1% of cases at the lowest quartile and 60.4% at the highest quartile of hospitals meeting criteria for all bundle processes. Overall, the rate of any complication was 6.8% and major complication 2.3%. The rate of hospital readmissions was 3.6%. After adjustment for confounders, in cases where all bundle criterion were met compared to cases where all bundle criterion were not met, the rate of any complications increased from 4.3% to 7.8% ($p<0.001$), major complications increased from 1.7% to 2.6% ($p<0.001$) and readmissions increased from 2.6% to 4.1% ($p<0.001$). After adjustment for confounders, hospitals with greater rates of meeting all four criteria were significantly associated with lower hospital-level rates of postoperative complications ($p<0.001$) and readmissions ($p<0.001$).

Conclusions—This multi-institutional evaluation reveals that reduced morbidity and readmission are associated with rates of bundle compliance. The proposed bundle is a surgical goal, not possible in every case, and there is significant variation in the proportion of cases meeting all four bundle processes in Michigan hospitals. Implementation of evidence-based process bundles at a healthcare system-level are worthy of prospective study to determine if improvements in patient outcomes are possible.

Condensation

Among hospitals in a statewide collaborative, hysterectomies meeting criteria for four evidence-based perioperative processes were associated with decreased postoperative complications and readmissions.

Introduction

The use of team-based interventions to improve processes of care has been shown to improve outcomes and has been adopted by healthcare in the past decade. For example, use of a process bundle in the ICU comprised of evidence-based quality measures dramatically decreased catheter-related bloodstream infections.¹ In surgical settings, adherence to a safety checklist published by the World Health Organization has been shown to decrease in-hospital mortality in a variety of healthcare environments.^{2, 3} In gynecologic surgery, use of evidence-based guidelines, such as appropriate preoperative antibiotic prophylaxis, has been shown to decrease the risk of infectious complications.⁴

Collective bundling of more than one relevant evidence-based process may help optimize outcomes and has been shown to decrease surgical site infection rate in gynecologic oncology and colorectal surgery.⁵⁻⁷ However, evidence supporting the use of perioperative bundles for hysterectomy and what processes they might contain is lacking despite the fact that over 400,000 women per year undergo the procedure in the U.S.⁸ Therefore, the aim of our study was to evaluate a perioperative bundle of evidence-based processes for benign hysterectomy and retrospectively evaluate its impact on postoperative outcomes using a statewide hysterectomy database.

The statewide hysterectomy database used to evaluate the perioperative bundle of evidence-based processes was the Michigan Surgical Quality Collaborative (MSQC). The MSQC collects and analyzes perioperative data at member hospitals to help identify and develop areas for quality improvement. Successful MSQC projects include a bundle of perioperative care process for colectomy associated with reducing surgical site infection, readmissions, and healthcare costs.⁷ Building upon evidence from prospective trials in ICU and operating rooms and the MSQC colectomy model, we developed a bundle of perioperative care processes found to reduce complications among women undergoing hysterectomy. Using data from the MSQC, we modeled how criteria for perioperative care processes are associated with 30-day postoperative complications and readmissions in a large cohort of patients who underwent hysterectomy in Michigan. This retrospective analysis allows for a large study sample to evaluate the utility of a process bundle before the expensive and time-consuming prospective interventional trial or new bundle implementation project is performed. This evidence may help guide the development future team-based interventions in gynecologic surgery to improve the patient-centered outcomes. Therefore, the present study retrospectively analyzes hysterectomy process bundle by preset criteria among MSQC hospitals and compares the presence of these processes with risk-adjusted rate of 30-day postoperative complications and readmissions.

Methods

Benign hysterectomies performed at participating Michigan Surgical Quality Collaborative (MSQC) member hospitals between January 2013 and January 2015 were included in the analysis. MSQC is a statewide initiative that collects and analyzes perioperative data at member hospitals to help identify and develop areas for quality improvement. Funding is provided by Blue Cross Blue Shield of Michigan. Data is systematically collected by trained

nurse abstractors at 63 different hospitals across the state. These hospitals represent 47% of the hospitals in the state of Michigan. Detailed methods of the registry's data collection have been described previously.^{7, 9} A sample methodology is used to select patients to minimize selection bias, and Current Procedural Terminology (CPT) codes, as well as medical record information, are reviewed by nurses to track 30-day outcomes. The University of Michigan Institutional Review Board deemed the present study "not regulated" (HUM00100436).

The main predictor of interest was the number of perioperative processes meeting criteria. Each of the criteria was a specific process goal for hysterectomy care quantified in MSQC data. Based on the colectomy bundle model and adapting it to specific issues associated with hysterectomy, we considered use of recommended antibiotics, minimally invasive surgical approach, and short operative time. We added the avoidance of hemostatic agents, because there is observational evidence¹⁰⁻¹² associating them with post-operative complications and their use in this database is common (15%) in this database. All these items are considered goals for care and not compulsory; the absence of these measures is valid and justified on an individual basis due to a variety of patient and surgical factors. The following dichotomous processes were included in the hysterectomy process bundle: the use of minimally invasive (MIS) approach (either vaginal or laparoscopic)¹³⁻¹⁵, the use of recommended preoperative antibiotics¹⁶⁻¹⁸, a target operative time of under 120 minutes (the approximate median time in the study sample)¹⁹⁻²¹, and the avoidance of hemostatic agents (HA)¹⁰⁻¹². Preoperative antibiotics were defined as recommended if they are included in American College of Obstetricians and Gynecologists and/or the Surgical Care Improvement Project and this methodology has been previously described. (4) The use of hemostatic agents was defined as any recorded use of oxidized cellulose polymer, thrombin-containing gelatin matrix, or absorbable gelatin compressed sponge products as recorded in the operative note. In an exploratory analysis, we also examined how including a longer surgical time criteria (180 minutes) in the bundle of processes would be associated with improved outcomes.

The main outcomes of interest were the rate of any postoperative complications, major postoperative complications, and hospital readmissions within 30 days of initial surgery. Postoperative complications include acute renal failure, blood transfusion within 72 hours of surgery, cardiac arrest requiring cardiopulmonary resuscitation, central line infection, cerebral vascular accident, death, deep vein thrombosis, intestinal obstruction, myocardial infarction, pelvic abscess, pulmonary embolism, rectovaginal fistula, sepsis, surgical site infection (superficial, deep and organ-space), unplanned intubation, ureteral obstruction, ureterovaginal fistula, urinary tract infection (UTI), vaginal cuff dehiscence, vaginal cuff infection, and vesicovaginal fistula. Major complications include all postoperative complications but exclude blood transfusion, UTI, and superficial surgical site infection. Postoperative hospital readmissions were defined as an inpatient hospital readmission.

Because the validity of a retrospective analysis is threatened by confounding between the outcome and unmeasured variables, a broad set of covariates was included in the statistical analysis. These included age, race, body mass index, surgical indication (defined as eight categories including abnormal uterine bleeding, endometrial hyperplasia or cervical dysplasia, family history, fibroids, pelvic mass, pelvic pain and endometriosis, prolapse, or other), and an age-adjusted Charlson comorbidity score (increasing score equals greater

morbidity).²² Surgical complexity was quantified by the following variables: pathology measured uterine weight, the sum total procedure relative value units (RVUs) based on codes from the CPT Coding System, 4th edition for other (separate procedures performed by the primary surgeon such as lysis of adhesions) and concurrent (procedures performed by a separate surgeon such as panniculectomy) surgical procedures, as well as the sum total number of other and concurrent procedures (excluding cystoscopy).

Data were aggregated at the hospital level and the percentage of cases that met criteria for all bundle items was determined. Risk-adjusted outcomes were calculated using multivariable logistic regression with Huber-Eicker-White robust standard errors to adjust for hospital-level clustering present in the collected data. Bonferroni's method was used to account for making multiple comparisons between outcomes.²³ To examine the magnitude of the bundles effect on the probability of postoperative complications or readmissions, the predicted probability, or mean marginal effect, was derived from the logistic regression models. The mean marginal effects represent the predicted probability of the outcome or the percentage-point changes in outcomes due to the bundle usage, and they are useful when interpreting the results of a logistic regression model in a clinical context. Stata 14.0 software was used for all analyses.

Results

During the study period, data from 16,515 benign hysterectomies performed at 63 hospitals in the state of Michigan were available for analysis. Cases from 7 low volume hospitals (<50 hysterectomies over the study period) were excluded, which totaled 170 cases. In 59 hysterectomy cases, criteria for none (0/4) of the perioperative process measures were met. The small size of this group precluded meaningful analysis, and these cases were therefore excluded, leaving 16,286 cases in the final analysis.

Bundle criteria met amongst all cases and at the hospital level were analyzed. Among all hysterectomies reviewed, 33.6% met criteria for all bundle processes; however, there was wide variation in the rate among the 56 hospitals in the study sample with 9.1% of cases at the lowest quartile and 60.4% at the highest quartile of hospitals meeting criteria for all bundle processes. (Figure 1).

The least variation in practice was seen with the appropriate antibiotic bundle process, which occurred on average in 91.3% of cases. In the lowest quartile, 76.5% of cases received appropriate antibiotics and 98.6% of cases received them in the highest quartile hospitals. A minimally invasive approach was utilized in an average of 77.9% of cases; however, only 57.9% of cases were performed with a MIS approach in the lowest quartile of hospitals and 92.7% of cases in the highest quartile of hospitals. Variation increased in the proportion of cases performed not meeting hemostatic agent and operative time criteria. On average, 84.6% of cases were performed without hemostatic agents, however in the lowest quartile of hospitals 59.3% of hysterectomies were performed without hemostatic agents, and in the highest quartile of hospitals 93.7% of hysterectomies were performed without their use. The largest amount of practice variation occurred in the procedure length criterion. The average proportion of cases per hospital with operative times less than 120 minutes was 53.9%, with

the lowest quartile of hospitals performing 26.2% of surgeries and the upper quartile of hospitals performing 83.2% of surgeries in fewer than two hours (Figure 1).

As expected, cases that met criteria for 1, 2, 3, and 4 bundle items differed based on demographic and perioperative characteristics (Table 1). Caucasian race was associated with increasing numbers of bundle criteria met and African American race was associated with decreased numbers bundle criteria met. Diabetes, hypertension, body mass index (BMI), a lower Charlson Comorbidity Score, and the presence of adhesions were less likely as the number of bundle criteria increased. A full comparison of the bundle items and individual processes are show in Table 2.

5,476 (33.6%) cases met all four bundle criteria, and 10,810 (66.4%) cases did not meet all four bundle criteria. After controlling for patient demographics, surgical factors, and hospital-level clustering effects, when all bundle criteria were met compared to when all bundle criteria were not met the rate of any complications increased from 4.3% to 7.8% ($p<0.001$), major complications increased from 1.7% to 2.6% ($p<0.001$) and readmissions increased from 2.6% to 4.1% ($p<0.001$).

After controlling for these demographic, medical, and surgical differences, the adjusted rates of complications were seen to decrease as more bundle criteria were met (Table 3). The rate of any postoperative complication significantly decreased from 15.1% with single bundle process criterion met, to 4.1% with all 4 bundle processes meeting criteria ($p<0.001$). Major complication rates also significantly decreased as bundle criteria are met starting at 3.6% when a single criteria is met and decreasing to 1.6% when all four criteria of the bundle is met ($p<0.015$). Rates of hospital readmission decreased as well from 4.6% when only a single bundle criterion was met to 2.5% when all four criteria were present ($p<0.07$).

For each individual combination of bundle processes, the outcomes for each combination of bundle processes were analyzed. The most common combination was full bundle compliance comprising 33.6% of the total sample, followed by absence of surgical time criterion (28.7%) and absence of minimally invasive criterion (8.9%) (Table 4). Of all cases meeting three of four criteria, 64.2% were cases with surgical time absent, 19.8% with MIS approach absent, 9.0% with hemostatic agents criterion not met, and 3.1% without appropriate antibiotics. There were significant differences between the postoperative outcomes of these combinations compared to full bundle compliance (see Table 4). Of the all combinations with only one criterion missing, not meeting the hemostatic agents criterion was associated with the greatest increase in major complications, 2.6 percentage points ($p=0.037$) compared to meeting full bundle criteria. Of the common bundle combinations when two out of four criteria were met, the absence of the surgical time and MIS approach criteria together increased any postoperative complication by 9.9 percentage points ($p<0.001$) and increased hospital readmissions by 3.1 percentage points ($p<0.001$); the most of any combination in comparison compared to meeting full bundle criteria.

Because the choice of 120 minutes as the surgical time criterion was based on median time in this cohort, we performed a sensitivity analysis to examine the effect of a longer surgical time, 180 minutes, as a part of the process bundle. We repeated the analysis (Appendix Table

1, Appendix Table 2, and Appendix Table 3). It did not change the results, though it does increase the predicted morbidity associated with missing this criterion.

When the hospital-level complete (all four) bundle criteria achievement was compared to the hospital-level complication and readmission rates, there was a significant correlation between meeting all of the bundle process criteria and having a lower rate of any and major complications (Pearson's correlation $R = -0.48$, $p < 0.001$, and $R = -0.40$, $p = 0.022$, respectively) as well as readmissions (Pearson's correlation $R = -0.49$, $p < 0.001$) (Figure 2).

Discussion

Morbidity and readmissions were associated with an evidence-based 4-item care process bundle in benign hysterectomy cases in a statewide database. There is a step-wise decrease in post-hysterectomy complications with the addition of each process. This effect is present after controlling for patient factors, surgical complexity, and hospital-level effects. We note a wide variation in practice between hospitals, which does not appear to be due solely to differences in patient factors or surgical pathology. This variation in practice and the bundle's association with lower complication rates presents an opportunity for action and quality improvement.

Our major finding was that the presence of some or all of these bundle items improves outcomes in an incremental and clinically significant fashion. Related to this finding, there was wide variation in the prevalence of these processes among hospitals. This lends evidence to practice-, hospital-, and system- level implementations of perioperative process bundles in gynecologic surgery. Quality improvement bundles have been shown to dramatically improve outcomes as in the case of the World Health Organization's Safe Surgery Saves Lives program. In this program, instituting a surgical checklist emphasizing a cooperative team based approach as well as other patient safety issues reduced postoperative complications and mortality in surgical patients worldwide.² In gynecology, recent bundle studies including pre-, intra-, and postoperative processes, including attention to appropriate antibiotic use, have shown a reduced risk of surgical site infection (SSI) after implementation.^{4, 6}

Given the success of team-based interventions such as checklists and bundle processes in improved safety across many settings as mentioned above, it is worthwhile to explore expanding their use into gynecologic surgery.⁶ Often the individual processes involved in a care bundle are small items whose benefit is well-established. At other times, they represent ideals that are not always achievable. In these latter situations, it is critical to remember that the processes included in the bundle are not meant to be punitive but are rather intended to guide treatment and clinical decision making. While we chose bundle items based on associations with surgical site infection, other items may be included that have evidence for decreasing postoperative complications like prehabilitation before surgery, VTE prophylaxis, early ambulation, and chlorhexidine gluconate-based skin hygiene.^{6, 24–26} Implementing the concept of a bundle of processes into institution-wide practice may be a relatively simple intervention that identifies and minimizes unnecessary variation in care to improve patient outcomes.

The bundle items in this study were chosen for their existing supporting evidence, known existing variation, and actionable nature. However, we recognize that there are cases where a minimally invasive approach may be impractical, surgical time of less than two hours not feasible, and avoidance of hemostatic agents neither appropriate nor warranted. Therefore, the purpose of this bundle is to draw attention to an ideal where as many of these processes are met whenever possible. Introducing a set of team-based interventions for the surgeon and surgical team can help to ensure that these processes are fulfilled to the best of the team's ability for every patient.

Limitations of this study are important to consider. Its retrospective design prevents us from establishing causation. Undertaking a prospective trial would require an extremely large trial, and this analysis provides information regarding the estimated effect size of such an intervention. The present analysis was limited to benign hysterectomy, and therefore it may not be applicable to oncology patients or other benign gynecological procedures. It is also possible that the observed findings could be in part due to factors that were not measured in the current study. While we used RVUs, concurrent procedures and specimen weight to help adjust for surgical complexity, information regarding surgeon skill, experience or volume was not available due to the sampling methodology of MSQC. Additionally, not every bundle item is applicable to every clinical scenario, as in the case of surgical approach. A minimally invasive approach should always be considered, but the authors recognize that this is not always possible. For similar reasons, surgical time less than 120 minutes may not be possible, and such a metric would be unreasonable as a blanket policy at a practice, hospital, or payer level.

In conclusion, this analysis describes the benefits of a simple perioperative process bundle in decreasing postoperative complications and readmissions. In a large, multi-hospital sample, we note significant hospital-level variation in each of the individual processes. Where variation is found, it is important to examine surgical and system practices in order to improve care, to reduce morbidity, and to improve the population health of women undergoing surgery.

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Appendix

Appendix Table 1

Patient and Operative Characteristics by number of total compliant hysterectomy process bundle items including operative time criteria less than 180 minutes

		Number of Bundle Items*			
		1	2	3	4
N		228 (1.4%)	1831 (11.2%)	5718 (35.1%)	8509 (52.3%)
Age					
	Under 65 yo	198 (86.8%)	1676 (91.5%)	5230 (91.5%)	7750 (91.1%)
Race					
	White	128 (56.1%)	1161 (63.4%)	4015 (70.2%)	7076 (83.2%)
	Black	83 (36.4%)	555 (30.3%)	1326 (23.2%)	911 (10.7%)
	Other	17 (7.5%)	115 (6.3%)	377 (6.6%)	522 (6.1%)
BMI (SD)		33.5 (8.4)	32.2 (8.5)	31.2 (7.9)	30.1 (7.5)
Tobacco Use		57 (25.0%)	462 (25.2%)	1418 (24.8%)	1979 (23.3%)
Hypertension		100 (43.9%)	664 (36.3%)	1694 (29.6%)	2113 (24.8%)
Diabetes		25 (11.0%)	232 (12.7%)	554 (9.7%)	679 (8.0%)

		Number of Bundle Items*			
		1	2	3	4
Charlson Comorbidity Index	4	59 (25.9%)	373 (20.4%)	963 (16.8%)	1273 (15.0%)
Surgical Indication, 5 ways					
	Fibroids	72 (31.7%)	769 (42.2%)	2242 (39.3%)	2375 (28.0%)
	Pelvic Mass	78 (34.4%)	314 (17.2%)	518 (9.1%)	456 (5.4%)
	Prolapse	10 (4.4%)	76 (4.2%)	472 (8.3%)	999 (11.8%)
	Endometrial Hyperplasia or Cervical Dysplasia	10 (4.4%)	71 (3.9%)	211 (3.7%)	408 (4.8%)
	Pelvic Pain and Endometriosis	10 (4.4%)	129 (7.1%)	500 (8.8%)	941 (11.1%)
	Abnormal Uterine Bleeding	25 (11.0%)	254 (14.0%)	959 (16.8%)	1996 (23.5%)
	Family History	17 (7.5%)	94 (5.2%)	425 (7.5%)	641 (7.6%)
	Other	10 (4.4%)	114 (6.3%)	373 (6.5%)	675 (8.0%)
Surgical Approach, 5 ways					
	Abdominal	200 (87.3%)	1275 (69.6%)	2124 (37.2%)	0 (0%)
	Laparoscopic	10 (4.4%)	115 (6.3%)	598 (10.5%)	1283 (15.1%)
	Vaginal	10 (4.4%)	41 (2.2%)	398 (7.0%)	1665 (19.6%)
	LAVH	10 (4.4%)	79 (4.3%)	494 (8.6%)	1120 (13.2%)
	Robotic	16 (7.0%)	321 (17.5%)	2104 (36.8%)	4441 (51.2%)
Presence Adhesions					
	None/Mild	110 (48.3%)	1119 (61.1%)	4174 (73.0%)	7038 (82.8%)
	Moderate	37 (16.2%)	290 (15.8%)	435 (12.9%)	873 (10.3%)
	Severe	81 (33.5%)	422 (23.1%)	809 (14.2%)	598 (7.0%)
Total other and concurrent RVUs (SD)		8.5 (17)	2.8 (8.2)	1.6 (5.8)	0.6 (3.2)
Pathology measured specimen mass (SD)		543 (1078)	371 (593)	299 (515)	141 (143)
Mean number of other procedures (SD)		1.4 (1.6)	0.9 (1.1)	0.8 (1.1)	0.8 (1.0)
Mean number of concurrent procedures (SD)		0.7 (1.3)	0.3 (0.7)	0.2 (0.6)	0.1 (0.3)

* Patient with zero bundle items (59 patients) compliant were excluded due to extremely small sample size.

† RVU, relative value units

Appendix Table 2

Compliant items by number of total compliant hysterectomy process bundle items including operative time criteria less than 180 minutes

Number of bundle items	Number of Bundle Items*			
	1	2	3	4
N	228	1831	5718	8509
Minimally Invasive Approach	28 (12.3%)	556 (30.4%)	3594 (62.9%)	8509 (100%)
Appropriate Preoperative Antibiotics	142 (55.7%)	537 (29.1%)	780 (13.5%)	8611 (100%)
Surgical time less than 180 minutes	35 (15.4%)	1136 (62.0%)	4080 (71.4%)	8509 (100%)
Avoidance of hemostatic agents	52 (22.8%)	672 (36.7%)	4537 (79.4%)	8509 (100%)

* Patient with zero bundle items (59 patients) compliant were excluded due to extremely small sample size.

Appendix Table 3

Predicted Absolute and Relative Rates* of Complications and Readmissions by Compliance with Bundle† Processes

Outcome		Number of Bundle Items*			
		1	2	3	4
Any Postoperative Complication	Absolute rate, %	16.2	11.4	7.6	4.5
	Difference, percentage points	11.7 [†]	6.8 [†]	3.1 [†]	Reference
Major Postoperative Complication	Absolute rate, %	4.3	3.4	2.7	1.6
	Difference, percentage points	2.7 ^{//}	1.7 ^{//}	1.0 [†]	Reference
Hospital Readmission	Absolute rate, %	3.7	5.1	4.2	2.8
	Difference, percentage points	0.9	2.3 [§]	1.4 [†]	Reference

* Rates are adjusted for the following covariates: age, race, body mass index, comorbidities, surgical indication, presence of intra-abdominal adhesions, total relative value units of other and concurrent procedures, total number of other and concurrent procedures, and uterine specimen mass, and hospital-level clustering. Patient with zero bundle items (59 patients) compliant were excluded due to extremely small sample size.

† Bundle items include: guideline-appropriate preoperative antibiotics, minimally invasive surgical approach, short operative duration (less than 180 minutes), and absence of intraoperative hemostatic agent use.

[†] p<0.001

[§] p<0.01

^{//} p<0.05

Figure 1. MSQC Hospitals rank ordered by percent of benign hysterectomies meeting each process in the process bundle

Panel A shows the study hospitals rank order by proportion of hysterectomies meeting the appropriate antibiotics criterion. Panel B shows the study hospitals rank order by proportion of hysterectomies meeting the absence of hemostatic agent criterion. Panel C shows the study hospitals rank order by proportion of hysterectomies meeting the minimally invasive surgical approach criterion. Panel D shows the study hospitals rank order by proportion of hysterectomies meeting the surgical time less than 120 minutes criterion.

Figure 2. Adjusted rates of Complications and Hospital Readmissions in MSQC Hospitals Ranked by Complete Four Bundle Process Achievement

Hospitals across MSQC are ordered by achievement of all four bundle processes on the right axis. Rate of complications is on the left axis with 95% confidence intervals. As the rate of meeting bundle criteria increases, there is a declining trend in complications (Pearson's correlation $R = -0.48$, $p = 0.0002$ for Any Complications, and Pearson's correlation $R = -0.40$, $p = 0.0022$ for Major Complications) and hospital readmissions (Pearson's correlation $R = -0.49$, $p = 0.0001$).

Table 1
Patient and Operative Characteristics by number of total criteria met in hysterectomy process bundle items

	Number of Bundle Items*			
	1	2	3	4
N	704 (4.3%)	2829 (17.4%)	7277 (44.7%)	5476 (33.6%)
Age under 65 years old	625 (88.8%)	2623 (92.7%)	6620 (91.0%)	4986 (91.1%)
Race				
White	405 (57.5)	1843 (65.2%)	5321 (73.1%)	4811 (87.9%)
Black	257 (36.5%)	816 (28.8%)	1389 (19.1%)	413 (7.5%)
Other	42 (6.0%)	170 (6.0%)	572 (7.8%)	252 (4.6%)
Body Mass Index (kg/m2) (SD)	33.2 (8.3)	32.1 (8.3)	30.7 (7.8)	29.7 (7.3)
Tobacco Use	179 (23.4%)	694 (24.5%)	1702 (23.4%)	1341 (24.5%)
Hypertension	285 (40.5%)	964 (34.1%)	2046 (28.1%)	1276 (23.3%)
Diabetes	96 (13.6%)	315 (11.1%)	659 (9.1%)	420 (7.7%)
Charlson Comorbidity Index	165 (23.4%)	510 (18.0%)	1198 (16.5%)	795 (14.5%)
Surgical Indication				
Fibroids	286 (40.9%)	1178 (41.8%)	2686 (37.0%)	1308 (23.9%)
Pelvic Mass	176 (25.2%)	383 (13.6%)	519 (7.2%)	288 (5.3%)
Prolapse	19 (2.7%)	127 (4.5%)	776 (10.7%)	635 (11.6%)
Endometrial Hyperplasia or	27 (3.8%)	113 (4.0%)	287 (4.0%)	272 (5.0%)

	Number of Bundle Items*			
	1	2	3	4
Cervical Dysplasia				
Pelvic Pain and Endometriosis	24 (3.4%)	242 (8.6%)	662 (9.1%)	649 (11.9%)
Abnormal Uterine Bleeding	90 (12.9%)	417 (14.8%)	1340 (18.5%)	1387 (25.4%)
Family History	39 (5.6%)	189 (6.7%)	520 (7.2%)	429 (7.9%)
Other	38 (5.4%)	171 (6.1%)	465 (6.4%)	497 (9.1%)
Surgical Approach				
Abdominal	613 (87.1%)	1543 (54.5%)	1443 (19.8%)	0 (0%)
Laparoscopic	20 (2.8%)	243 (8.6%)	942 (12.9%)	799 (14.6%)
Vaginal	20 (2.8%)	87 (3.1%)	722 (9.9%)	1291 (23.6%)
LAVH	20 (2.8%)	223 (7.9%)	754 (10.4%)	708 (12.9%)
Robotic	55 (7.8%)	733 (25.9)	3418 (46.4%)	2678 (48.9%)
Presence Adhesions				
None/Mild	402 (57.1%)	1847 (65.3%)	5516 (75.8%)	4676 (85.4%)
Moderate	94 (13.4%)	442 (15.6%)	874 (12.0%)	525 (9.6%)
Severe	208 (29.6%)	540 (29.1%)	887 (12.2%)	275 (5.0%)
Total other and concurrent RVU[†] (SD)				
	3.9 (11.1)	2.3 (7.3)	1.3 (5.2)	0.5 (2.6)
Pathology measured specimen weight in grams (SD)				
	462 (818)	359 (613)	234 (369)	122 (120)
Mean number of other procedures (SD)				
	1.1 (1.4)	0.8 (1.0)	0.9 (1.1)	0.7 (0.9)

Number of Bundle Items*				
	1	2	3	4
Mean number of concurrent procedures (SD)	0.4 (0.9)	0.3 (0.7)	0.2 (0.5)	0.1 (0.3)

* Patients with zero bundle items (59 patients) met were excluded due to extremely small sample size. Values that are based on ten or fewer participants were assigned a value of 10 because of privacy restrictions. In the case of single cell in a column or row being suppressed, the second and/or third lowest count cells will also be assigned a value of less than nearest multiple of ten to prevent the ability to calculate the value of the suppressed cell.

[†]RVU, relative value units

Table 2

Compliant items by number of total compliant hysterectomy process bundle items

Number of bundle items	Number of Bundle Items [*]			
	1	2	3	4
N	704	2829	7277	5476
Minimally Invasive Approach	91 (12.9%)	1286 (45.5%)	5834 (80.2%)	5476 (100%)
Appropriate Preoperative Antibiotics	439 (62.4%)	2178 (71.0%)	6770 (93.0%)	5476 (100%)
Surgical time less than 120 minutes	35 (5.0%)	660 (23.3%)	2606 (35.8%)	5476 (100%)
Avoidance of hemostatic agents	139 (19.7%)	1534 (54.2%)	6621 (91.0%)	5476 (100%)

* Patients with zero bundle items (59 patients) met were excluded due to extremely small sample size.

Table 3

Predicted Absolute and Relative Rates^{*} of Complications and Readmissions by Number of Bundle[†] Criteria Met

Outcome	Number of Bundle Items [*]			
	1	2	3	4
Any Postoperative Complication	Absolute rate, %			
	15.1	9.5	6.4	4.1
	Difference, percentage points			
	11.0 [‡]	5.4 [‡]	2.3 [‡]	Reference
Major Postoperative Complication	Absolute rate, %			
	3.6	2.9	2.3	1.6
	Difference, percentage points			
	2.0	1.3 [§]	0.7	Reference
Hospital Readmission	Absolute rate, %			
	4.6	4.7	3.8	2.5
	Difference, percentage points			
	2.1	2.2 [‡]	1.2 [‡]	Reference

^{*} Rates are adjusted for the following covariates: age, race, body mass index, comorbidities, surgical indication, presence of intra-abdominal adhesions, total RVUs of other and concurrent procedures, total number of other and concurrent procedures, and uterine specimen mass, and hospital-level clustering. Patients with zero bundle items (59 patients) met were excluded due to extremely small sample size.

[‡] Bundle items include: guideline-appropriate preoperative antibiotics, minimally invasive surgical approach (MIS), short operative duration (less than 120 minutes), and absence of intraoperative hemostatic agent use (HA).

[‡] p<0.001

[§] p=0.001-<0.01

^{||} p=0.01-<0.05

Table 4
Predicted Absolute and Relative Rates^{*} of Complications and Readmissions by Most Common Bundle[†] Combinations

Most Common Bundle Combinations									
	All criteria met	All criteria met except surgical time	All criteria met except MIS approach	All criteria met except HA	All criteria met except antibiotics	All criteria met except surgical time and MIS approach	All criteria met except surgical time and HA		
Bundle process number	4	3	3	3	3	2	2		
N (percent of all cases)	5476 (33.6%)	4671 (28.7%)	1443 (8.9%)	656 (4.0%)	507 (3.1%)	964 (5.9%)	807 (5.0%)		
Percent of Each Bundle Outcome	100%	64.2%	19.8%	9.0%	7.0%	34.1%	28.5%		
Any Postoperative Complication	Absolute rate, % Difference, percentage points	5.7	9.4	6.3	4.6	13.9	7.9		
	Reference	1.7 ^{//}	5.4 [‡]	2.3	0.6	9.9 [‡]	3.9 ^{//}		
Major Postoperative Complication	Absolute rate, % Difference, percentage points	2.0	2.5	4.2	2.4	3.4	3.6		
	Reference	0.4	0.9	2.6 ^{//}	0.8	1.8	2.0 ^{//}		
Hospital Readmission	Absolute rate, % Difference, percentage points	3.4	4.3	5.4	3.5	5.6	5.5		
	Reference	0.9	1.7 ^{//}	2.8 [‡]	0.9	3.1 [‡]	3.0 ^{//}		

^{*} Rates are adjusted for the following covariates: age, race, body mass index, comorbidities, surgical indication, presence of intra-abdominal adhesions, total relative value units of other and concurrent procedures, total number of other and concurrent procedures, and uterine specimen mass, and hospital-level clustering. Patient with zero bundle items (59 patients) compliant were excluded due to extremely small sample size.

[†] Bundle items include: guideline-appropriate preoperative antibiotics, minimally invasive surgical (MIS) approach, short operative duration (less than 120 minutes), and absence of intraoperative hemostatic agent (HA) use.

[‡] p<0.001

[§] p=0.001-<0.01

^{//} p=0.01-<0.05