DEPARTMENT OF ANESTHESIOLOGY

JOURNAL CLUB

Tuesday December 4th, 2018
1800 HOURS

LOCATION:
Pan Chancho Restaurant – Private Dining Room
44 Princess Street

PRESENTING ARTICLES:
Dr. Joel Parlow & Dr. Jordan Leitch

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SUGGESTED GUIDELINES FOR CRITICAL APPRAISAL OF PAPERS
ANESTHESIOLOGY JOURNAL CLUB
QUEEN'S UNIVERSITY
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Two presenters will be assigned to choose and present summaries of their papers. Ideally the two papers will represent similar topics but contrasting research methodologies. The focus remains on critical appraisal of the research and manuscript, more than on the actual contents of the article. Each presenter will then lead an open discussion about the article, based around the guidelines below. The object is to open up the appraisal to wide discussion involving all participants.

GENERAL

1. Title of paper: Does it seem like an important problem? Does it reflect the purpose/results?
2. Authors, institution and country of origin

INTRODUCTION

1. What is the problem being addressed?
2. What is the current state of knowledge of the problem studied?
3. What is the hypothesis being tested?
4. How does testing the hypothesis help solve the stated problem?

METHODOLOGY

1. Study design:
    a) Clinical trial vs. systematic review/meta-analysis
    b) Prospective vs. retrospective
    c) Observational vs. Experimental
    d) Randomized or not
    e) Blinded or not

2. Population studied:
    a) Human, animal, other
    b) Justification
    c) Control groups: experimental vs. historical
    d) Is the sample size/power calculated, and how?
    e) Is the population similar to your own practice?
    f) Single vs. multi-centre

3. Is the study ethically sound?
    a) Clinical equipoise
    b) Does treatment meet standard of care (esp controls)?
    c) Appropriate consent and institutional ethics approval

4. Exclusions: what groups are excluded and why?

5. Experimental protocol
    a) Is it designed to test the hypothesis?

b) Is it detailed enough to be reproducible?
c) Is the methodology validated?
d) Are the drugs/equipment used detailed?
e) How does the randomization take place?

6. What are the primary endpoints?
7. Is power sufficient to justify secondary endpoints?
8. Is the protocol clinically relevant?
9. Data collection and analysis
10. Statistical analysis: Is it appropriate? Are results

RESULTS

1. Are the groups comparable?
2. Were any subjects/data eliminated?
3. Analyzed by intent to treat?
4. Are adequate details of results provided? - data, graphs, tables

DISCUSSION

1. What is the main conclusion of the study?
2. Do the results support this conclusion?
3. Do the results address the stated purpose/hypothesis of the study?
4. How do the authors explain the results obtained?
5. Are there any alternative interpretations to the data?
6. Are the results clinically as well statistically relevant?
7. How do the results compare with those of previous studies?
8. What do the results add to the existing literature?
9. What are the limitations of the methods or analysis used?
10. What are the unanswered questions for future work?

APPLICABILITY OF THE PAPER

1. Have you learned something important from reading this paper?
2. Will the results of this study alter your clinical practice?

Relationship between Intraoperative Hypotension, Defined by Either Reduction from Baseline or Absolute Thresholds, and Acute Kidney and Myocardial Injury after Noncardiac Surgery

A Retrospective Cohort Analysis

Vafi Salmasi, M.D., Kamal Maheshwari, M.D., M.P.H., Dongsheng Yang, M.A., Edward J. Mascha, Ph.D., Asha Singh, M.D., Daniel I. Sessler, M.D., Andrea Kurz, M.D.

ABSTRACT

Background: How best to characterize intraoperative hypotension remains unclear. Thus, the authors assessed the relationship between myocardial and kidney injury and intraoperative absolute (mean arterial pressure [MAP]) and relative (reduction from preoperative pressure) MAP thresholds.

Methods: The authors characterized hypotension by the lowest MAP below various absolute and relative thresholds for cumulative 1, 3, 5, or 10 min and also time-weighted average below various absolute or relative MAP thresholds. The authors modeled each relationship using logistic regression. The authors further evaluated whether the relationships between intraoperative hypotension and either myocardial or kidney injury depended on baseline MAP. Finally, the authors compared the strength of associations between absolute and relative thresholds on myocardial and kidney injury using C statistics.

Results: MAP below absolute thresholds of 65 mmHg or relative thresholds of 20% were progressively related to both myocardial and kidney injury. At any given threshold, prolonged exposure was associated with increased odds. There were no clinically important interactions between preoperative blood pressures and the relationship between hypotension and myocardial or kidney injury at intraoperative mean arterial blood pressures less than 65 mmHg. Absolute and relative thresholds had comparable ability to discriminate patients with myocardial or kidney injury from those without.

Conclusions: The associations based on relative thresholds were no stronger than those based on absolute thresholds. Furthermore, there was no clinically important interaction with preoperative pressure. Anesthetic management can thus be based on intraoperative pressures without regard to preoperative pressure. **(Anesthesiology 2017; 126:47-65)**

THE perioperative period is characterized by hemodynamic instability. Various degrees of hypotension are common during anesthesia and surgery and may cause organ ischemia. For example, hypotension contributes to oxygen supply–demand mismatch, which appears to be an important cause of postoperative myocardial infarction.[1–3] Furthermore, ischemia and reperfusion may contribute to postoperative acute kidney injury (AKI).[4–10] Myocardial perfusion is dependent on pressure gradient created by diastolic blood pressure[11]; vasomotor responses and regional ischemia in response to decreased blood pressure and cardiac output also contribute to ischemic renal injury.[12,13]

A systematic review of interventions to decrease the incidence of postoperative AKI demonstrated that avoiding hypotension reduced the incidence of AKI.[14] Consistent with the theory that intraoperative hypotension contributes to organ injury, hypotension, defined in various ways, is weakly associated with AKI[8,10] and strongly associated with myocardial infarction[8,15] and death.[9,16]

What We Already Know about This Topic

- Previous studies have demonstrated associations between low mean arterial pressure (MAP) and organ injury, with hypotension defined in terms of minutes or integrated pressures below various absolute thresholds.
- This study assessed the relationship between myocardial and kidney injury and intraoperative absolute (intraoperative MAP) and relative (reduction from preoperative pressure) MAP thresholds using retrospective data from a single institution.

What This Article Tells Us That Is New

- The associations based on relative mean arterial pressure thresholds were no stronger than those based on absolute thresholds. Furthermore, there was no clinically important interaction with preoperative pressure. These data suggest that anesthetic management can thus be based on intraoperative pressures without regard to preoperative pressure.

How best to characterize hypotension remains unclear, and there is no universal definition of hypotension. In a

This article is featured in "This Month in Anesthesiology," page 1A. This article has an audio podcast.

Submitted for publication April 22, 2016. Accepted for publication September 23, 2016. From the Departments of Outcomes Research and General Anesthesiology (V.S., K.M., D.I.S., A.K.), Departments of Quantitative Health Sciences and Outcomes Research (D.Y., E.J.M.), and Anesthesiology Institute, Cleveland Clinic, Cleveland, Ohio (A.S.).

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systematic review, for example, Bijker *et al.*[17] found 140 definitions for hypotension in 130 articles. A consequence was that the incidence of intraoperative hypotension ranged from 5 to 99% depending on the selected definition.

Several recent studies report associations between low mean arterial pressure (MAP) and organ injury, with hypotension defined in terms of minutes or integrated pressures below various absolute thresholds.[8–10,15] This approach differs from classical anesthesia teaching, which suggests keeping blood pressure within a relative 20% of preoperative values, apparently based on the theory that hypertensive patients require higher than normal pressures to adequately perfuse organs habituated to high pressures. Despite the frequency of this recommendation, it does not appear to be based on credible outcome evidence. Which characterization of blood pressure, absolute *versus* relative hypotension, is most related to organ injury remains unknown.

Therefore, we assessed the relationship between various absolute and relative characterizations of hypotension and myocardial injury after noncardiac surgery (MINS)[18] and AKI in adults having inpatient surgery. Absolute thresholds were characterized by the lowest MAP maintained for various durations and by time under various MAP thresholds. Relative hypotension was characterized by maximum percentage MAP decrease from baseline maintained for various durations and by time under various percentage reductions from baseline. We then evaluated the interaction between preoperative MAP and the relationships between intraoperative hypotension and MINS or AKI. Finally, we determined whether absolute or relative characterizations best predict MINS and AKI.

Materials and Methods

We conducted a retrospective cohort study using data from the Cleveland Clinic Perioperative Health Documentation System and Epic, electronic medical record-based registries of noncardiac surgery patients who had undergone surgery between January 6, 2005, and March 1, 2014, at the Cleveland Clinic, Cleveland, Ohio.

Inclusion criteria were as follows: (1) adults who had inpatient noncardiac surgery between January 6, 2005, and March 1, 2014; (2) preoperative and at least one postoperative serum creatinine measurement available within the first 7 postoperative days; (3) blood pressure recorded in the preanesthesia care evaluation clinic or other preoperative appointments within 6 months before surgery.

Exclusion criteria were as follows: (1) patients with chronic kidney disease defined as preoperative estimated glomerular filtration rate of less than 60 ml × min^{-1} × 1.73 m^{-2} or patients who were on dialysis; (2) urologic procedures including relief of urinary obstruction (International Classification of Diseases, Ninth Revision [ICD-9] codes of 5501, 5502, 5503, 5504, 5511, 5512, 560, 570, 5741, 5749, 602, 6021, 6029, 6096, 6097, 603, 604, 605, 6061, 6062, and 6069), nephrectomy (ICD-9 codes of 554, 5551, 5552, 5553, and 5554), or renal transplantation (ICD-9 codes of 5561 and 5569); (3) patients who had anesthesia for less than 60 min or missing baseline variables; (4) patients with invalid or unavailable data for more than 10 consecutive minutes.

Outcomes

1. MINS was defined as at least one increased postoperative value of either fourth-generation troponin T or creatine kinase-MB above the upper limit of normal in the 7 days after operation. The upper limit of normal was defined as 0.03 ng/ml for troponin T[18] and 8.8 ng/ml for creatine kinase-MB.[3] Eligible patients without postoperative cardiac enzyme determinations were assumed not to have acute myocardial injury.
2. Postoperative AKI was defined by increases in serum creatinine between preoperative and postoperative values. Preoperative creatinine was taken to be the last before surgery. Postoperative creatinine was taken to be the highest concentration measured within 7 postoperative days. According to the Acute Kidney Injury Network definition, patients were considered to have AKI if the postoperative value was either more than 1.5-fold or more than 0.3 mg/dl before surgery.[8]

Statistical Methods

MAP and Artifact Removing Algorithm. Intraoperative MAPs recorded in the Perioperative Health Documentation System cannot be modified by clinicians, but can be identified as artifactual. Invasive pressures were recorded at 1-min intervals; noninvasive pressures were recorded at 1- to 5-min intervals. We removed artifacts using the following rules, in order: (1) blood pressures documented as artifacts; (2) pressures out-of-range defined by (a) SBP greater than or equal to 300 or SBP less than or equal to 20 mmHg, (b) SBP less than or equal to DBP + 5 mmHg, or (c) DBP less than or equal to 5 mmHg or DBP greater than or equal to 225 mmHg; (3) abrupt changes defined by SBP change greater than or equal to 80 mmHg within 1 min in either direction or abrupt SBP changes greater than or equal to 40 mmHg within 2 min in both directions. Pressures between measurements were linearly interpolated.

Baseline MAP is described as the average of all MAP readings in the 6 months before surgery, excluding measurements during a hospital stay. Anesthesia time was defined as the interval between induction and emergence.

Confounding Variables. Potentially confounding variables are listed in table 1. We defined preexisting medical conditions using ICD-9 billing codes and included only those fulfilling at least one of the following: (1) appeared in the patient "problem list" with a date preceding the date of surgery; (2) appeared in an ICD-9 list before the index surgery; or (3) were flagged as a chronic ICD-9 condition based on Healthcare Cost and Utilization Project definitions. Because there were many types of surgical procedures, we characterized

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Table 1. Patient Baseline and Intraoperative Characteristics by Postoperative AKI and MINS

Factors	MINS (n = 1,760)	Non-MINS (n = 55,555)	*P* Values*	AKI (n = 3,215)	Non-AKI (n = 54,100)	*P* Values*
Female (%)	708 (40)	31,234 (56)	< 0.001	1,211 (38)	30,731 (57)	< 0.001
Race (%)			0.72			< 0.001
White	1,530 (87)	48,077 (87)		2,649 (82)	46,958 (87)	
Black	207 (12)	6,825 (12)		523 (16)	6,509 (12)	
Other	23 (1)	653 (1)		43 (1)	633 (1)	
Age, yr	67 ± 13	56 ± 15	< 0.001	61 ± 15	56 ± 16	< 0.001
Emergency (%)	257 (15)	1,817 (3)	< 0.001	311 (10)	1,763 (3)	< 0.001
ASA physical status (%)			< 0.001			< 0.001
1	7 (0)	1,217 (2)		21 (1)	1,203 (2)	
2	187 (11)	21,422 (39)		645 (20)	20,964 (39)	
3	1,023 (58)	29,290 (53)		1,887 (59)	28,426 (53)	
4	527 (30)	3,592 (6)		648 (20)	3,471 (6)	
5	16 (1)	34 (0)		14 (0)	36 (0)	
Use of arterial catheter (%)	1,411 (80)	21,729 (39)	< 0.001	1,892 (59)	21,248 (39)	< 0.001
Previous medical history						
Congestive heart failure	338 (19)	2,096 (4)	< 0.001	362 (11)	2,072 (4)	< 0.001
Valvular disease	195 (11)	2,345 (4)	< 0.001	236 (7)	2,304 (4)	< 0.001
Pulmonary circulation disease	101 (6)	979 (2)	< 0.001	121 (4)	959 (2)	< 0.001
Peripheral vascular disease	544 (31)	4,033 (7)	< 0.001	520 (16)	4,057 (8)	< 0.001
Hypertension	1,287 (73)	26,670 (48)	< 0.001	2,062 (64)	25,895 (48)	< 0.001
Paralysis	114 (6)	1,440 (3)	< 0.001	93 (3)	1,461 (3)	0.51
Other neurologic disorders	191 (11)	4,368 (8)	< 0.001	206 (6)	4,353 (8)	< 0.001
Chronic pulmonary disease	430 (24)	8,041 (14)	< 0.001	629 (20)	7,842 (15)	< 0.001
Diabetes	464 (26)	9,027 (16)	< 0.001	889 (28)	8,602 (16)	< 0.001
Hypothyroidism	215 (12)	6,615 (12)	0.69	385 (12)	6,445 (12)	0.92
Renal failure	79 (4)	542 (1)	< 0.001	136 (4)	485 (1)	< 0.001
Liver disease	151 (9)	3,039 (5)	< 0.001	396 (12)	2,794 (5)	< 0.001
Lymphoma	39 (2)	1,037 (2)	0.29	62 (2)	1,014 (2)	0.83
Metastatic cancer	156 (9)	4,191 (8)	0.040	334 (10)	4013 (7)	< 0.001
Solid tumor without metastasis	296 (17)	8,139 (15)	0.012	712 (22)	7,723 (14)	< 0.001
Rheumatoid arthritis/collagen vas	96 (5)	2,222 (4)	0.002	117 (4)	2,201 (4)	0.23
Coagulopthy	395 (22)	2,739 (5)	< 0.001	582 (18)	2,552 (5)	< 0.001
Obesity	397 (23)	13,183 (24)	0.25	940 (29)	12,640 (23)	< 0.001
Weight loss	326 (19)	3,345 (6)	< 0.001	634 (20)	3,037 (6)	< 0.001
Fluid and electrolyte disorders	95 (5)	2,109 (4)	< 0.001	190 (6)	2,014 (4)	< 0.001
Chronic blood loss anemia	109 (6)	1,054 (2)	< 0.001	142 (4)	1,021 (2)	< 0.001
Deficiency anemias	139 (8)	3,083 (6)	< 0.001	293 (9)	2,929 (5)	< 0.001
Alcohol abuse	83 (5)	1,222 (2)	< 0.001	175 (5)	1,130 (2)	< 0.001
Drug abuse	38 (2)	796 (1)	0.012	71 (2)	763 (1)	< 0.001
Psychoses	89 (5)	2,079 (4)	0.004	161 (5)	2,007 (4)	< 0.001
Depression	234 (13)	8,550 (15)	0.016	446 (14)	8,338 (15)	0.019
Cardiac medication history, n (%)						
ACE inhibitor	928 (53)	18,596 (33)	< 0.001	1,442 (45)	18,082 (33)	< 0.001
β-blocker	318 (18)	5,596 (10)	< 0.001	504 (16)	5,410 (10)	< 0.001
CA blocker	414 (24)	8,050 (14)	< 0.001	694 (22)	7,770 (14)	< 0.001
Diuretic	915 (52)	17,720 (32)	< 0.001	1,527 (48)	17,108 (32)	< 0.001
Angiotensin receptor blockers	291 (17)	5,928 (11)	< 0.001	513 (16)	5,706 (11)	< 0.001
Preoperative						
Preoperative hemoglobin, g/dl	12.7 ± 2.1	13.3 ± 1.8	< 0.001	12.6 ± 2.1	13.3 ± 1.8	< 0.001
Preoperative creatinine	0.9 ± 0.2	0.8 ± 0.2	< 0.001	0.9 ± 0.2	0.8 ± 0.2	< 0.001
Baseline EGFR, ml · min · 1.73 m^{-2}	94 ± 32	97 ± 28	< 0.001	98 ± 36	96 ± 28	0.016
Baseline MAP	92 ± 10	93 ± 10	0.12	94 ± 10	92 ± 9	< 0.001
Intraoperative						
Surgical time, h	5.1 ± 2.8	3.7 ± 2.0	< 0.001	4.7 ± 2.6	3.7 ± 2.0	< 0.001
Blood loss, cc	350 [100, 1,100]	150 [50, 300]	< 0.001	300 [100, 700]	150 [50, 300]	< 0.001

(*Continued*)

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Table 1. (Continued)

Factors	MINS (n = 1,760)	Non-MINS (n = 55,555)	*P* Values*	AKI (n = 3,215)	Non-AKI (n = 54,100)	*P* Values*
Top 10 surgical procedure, n (%)			< 0.001			< 0.001
Colorectal resection	84 (5)	4,795 (9)		414 (13)	4,465 (8)	
Arthroplasty knee	38 (2)	4,213 (8)		196 (6)	4,055 (8)	
Hysterectomy; abdominal and vaginal	20 (1)	3,390 (6)		86 (3)	3,324 (6)	
Spinal fusion	225 (13)	3,092 (6)		82 (3)	3,235 (6)	
Hip replacement	96 (5)	3,162 (6)		169 (5)	3,089 (6)	
Other OR upper GI therapeutic procedures	34 (2)	3,135 (6)		92 (3)	3,077 (6)	
Other OR lower GI therapeutic procedures	41 (2)	2,601 (5)		195 (6)	2,447 (5)	
Incision and excision of CNS	61 (3)	2,298 (4)		36 (1)	2,323 (4)	
Other OR GI therapeutic procedures	90 (5)	2,205 (4)		173 (5)	2,122 (4)	
Other OR therapeutic nervous system procedures	61 (3)	2,298 (4)		28 (1)	1,932 (4)	

Data are presented as mean ± SD, median [25th, 75th percentiles] or n (%).

**P* values from chi-square test, Student's *t* test, or Wilcoxon rank sum test, as appropriate.

ACE = angiotensin-converting enzyme; AKI = acute kidney injury; ASA = American Society of Anesthesiologists; CA = calcium channel; EGFR = estimated glomerular filtration rate; GI = gastrointestinal; MAP = mean arterial pressure; MINS = myocardial injury after noncardiac surgery; OR = operating room.

each procedure code into one of 231 clinically meaningful categories using the Agency for Healthcare Research and Quality's Clinical Classifications Software for Services and Procedures.[19] We then aggregated low-frequency event or nonevent categories (n < 10) into one group and used that as the reference group (a low-risk group).[20]

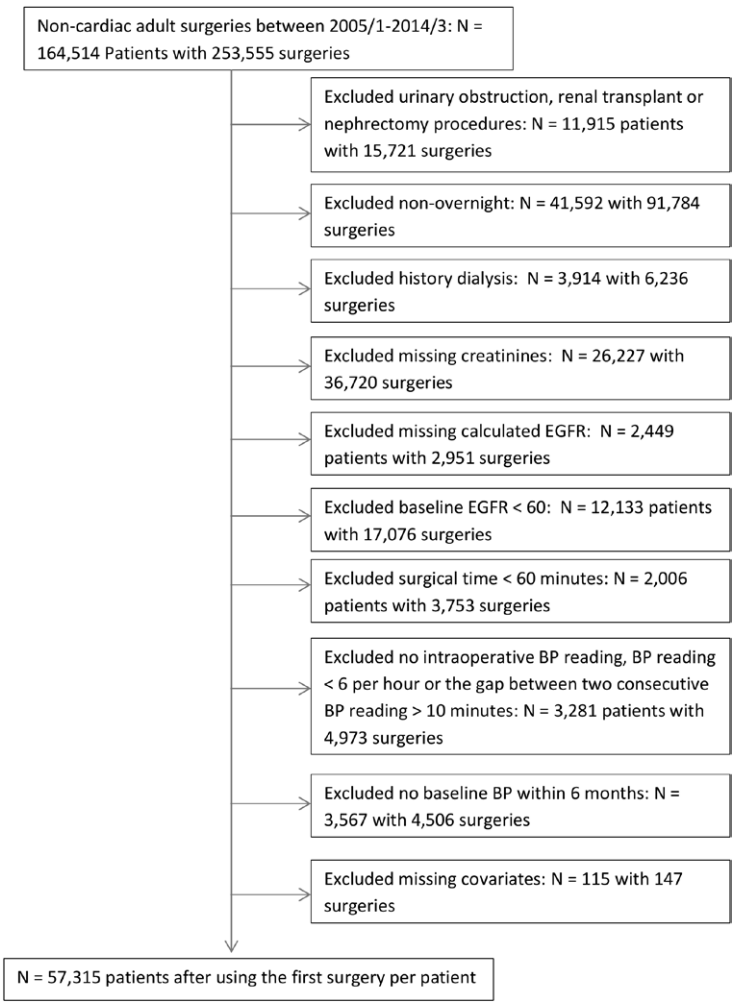

Fig. 1. Flow chart. BP = blood pressure; EGFR = estimated glomerular filtration rate.

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Table 2. Univariable Relationship between MAP Exposures and Outcomes

Exposures	MINS (n = 1,760)	Non-MINS (n = 55,555)	*P* Values*	AKI (n = 3,215)	Non-AKI (n = 54,100)	*P* Values*
Baseline MAP	92 ± 10	93 ± 10	0.12	94 ± 10	92 ± 9	< 0.001
Preinduction MAP	102 ± 18	101 ± 16	0.12	102 ± 17	101 ± 16	0.002
Intraoperative TWA-MAP	83 ± 10	84 ± 10	< 0.001	84 ± 10	84 ± 10	0.11
Lowest MAP, mmHg, for cumulative minutes						
≥ 1	53 ± 13	59 ± 11	< 0.001	56 ± 12	59 ± 11	< 0.001
≥ 3	58 ± 11	63 ± 10	< 0.001	60 ± 11	63 ± 10	< 0.001
≥ 5	60 ± 10	65 ± 9	< 0.001	62 ± 10	65 ± 9	< 0.001
≥ 10	63 ± 10	68 ± 9	< 0.001	65 ± 10	68 ± 9	< 0.001
Lowest % MAP decrease from baseline (%) for cumulative minutes,%						
≥ 1	42 ± 15	36 ± 13	< 0.001	40 ± 14	36 ± 13	< 0.001
≥ 3	37 ± 14	31 ± 12	< 0.001	35 ± 12	31 ± 12	< 0.001
≥ 5	34 ± 13	30 ± 11	< 0.001	33 ± 12	29 ± 12	< 0.001
≥ 10	31 ± 13	27 ± 11	< 0.001	30 ± 12	26 ± 11	< 0.001
Lowest MAP (mmHg) for sustained minutes						
≥ 1	53 ± 13	59 ± 11	< 0.001	56 ± 12	59 ± 11	< 0.001
≥ 3	61 ± 11	65 ± 9	< 0.001	62 ± 10	65 ± 9	< 0.001
≥ 5	64 ± 10	67 ± 9	< 0.001	65 ± 10	67 ± 9	< 0.001
≥ 10	70 ± 10	71 ± 9	< 0.001	70 ± 10	72 ± 9	< 0.001
Lowest % MAP decrease from baseline for sustained minutes, %						
≥ 1	42 ± 15	36 ± 13	< 0.001	40 ± 14	36 ± 13	< 0.001
≥ 3	33 ± 13	30 ± 11	< 0.001	33 ± 12	30 ± 11	< 0.001
≥ 5	30 ± 13	27 ± 11	< 0.001	30 ± 12	27 ± 11	< 0.001
≥ 10	24 ± 13	-22 ± 11	< 0.001	25 ± 12	22 ± 11	< 0.001
Minutes for MAP, mmHg						
< 75	67 [27, 139]	40 [15, 85]	< 0.001	54 [21, 114]	40 [15, 85]	< 0.001
< 70	36 [12, 80]	18 [4, 46]	< 0.001	27 [8, 67]	18 [4, 46]	< 0.001
< 65	15 [4, 39]	6 [0, 19]	< 0.001	10 [2, 32]	6 [0, 19]	< 0.001
< 60	5 [0, 16]	1 [0, 6]	< 0.001	3 [0, 12]	1 [0, 6]	< 0.001
< 55	1 [0, 6]	0 [0, 1]	< 0.001	0 [0, 4]	0 [0, 1]	< 0.001
< 50	0 [0, 2]	0 [0, 0]	< 0.001	0 [0, 1]	0 [0, 0]	< 0.001
Minutes for % MAP decrease from baseline						
< 20	57 [18, 127]	33 [9, 81]	< 0.001	50 [16, 113]	32 [9, 80]	< 0.001
< 30	13 [2, 42]	5 [0, 21]	< 0.001	10 [1, 36]	5 [0, 21]	< 0.001
< 40	1 [0, 7]	0 [0, 2]	< 0.001	0 [0, 6]	0 [0, 2]	< 0.001
< 50	0 [0, 1]	0 [0, 0]	< 0.001	0 [0, 0]	0 [0, 0]	< 0.001
TWA under MAP, mmHg						
< 75	1.9 [0.7, 4.0]	1.3 [0.4, 3.0]	< 0.001	1.6 [0.5, 3.5]	1.3 [0.4, 3.1]	< 0.001
< 70	0.9 [0.3, 2.0]	0.5 [0.1, 1.3]	< 0.001	0.6 [0.1, 1.6]	0.5 [0.1, 1.3]	< 0.001
< 65	0.3 [0.1, 0.9]	0.1 [0.0, 0.5]	< 0.001	0.2 [0.0, 0.6]	0.1 [0.0, 0.5]	< 0.001
< 60	0.1 [0.0, 0.3]	0.0 [0.0, 0.1]	< 0.001	0.0 [0.0, 0.2]	0.0 [0.0, 0.1]	< 0.001
< 55	0.0 [0.0, 0.1]	0.0 [0.0, 0.0]	< 0.001	0.0 [0.0, 0.0]	0.0 [0.0, 0.0]	< 0.001
TWA under % MAP decrease from baseline, mmHg						
< 10	5.5 [2.3, 10.7]	4.6 [1.8, 9.2]	< 0.001	5.2 [2.2, 10.0]	4.5 [1.7, 9.0]	< 0.001
< 15	3.1 [1.1, 7.1]	2.4 [0.7, 5.7]	< 0.001	2.9 [1.0, 6.5]	2.4 [0.7, 5.6]	< 0.001
< 20	1.6 [0.5, 4.1]	1.1 [0.2, 3.1]	< 0.001	1.4 [0.4, 3.7]	1.0 [0.2, 3.0]	< 0.001
< 25	0.7 [0.1, 2.2]	0.4 [0.0, 1.4]	< 0.001	0.6 [0.1, 1.9]	0.4 [0.0, 1.4]	< 0.001
< 30	0.3 [0.0, 1.0]	0.1 [0.0, 0.6]	< 0.001	0.2 [0.0, 0.8]	0.1 [0.0, 0.5]	< 0.001
AUC under MAP, mmHg * min						
< 75	520 [178, 1,104]	258 [73, 617]	< 0.001	383 [120, 908]	258 [73, 617]	< 0.001
< 70	227 [63, 559]	91 [13, 269]	< 0.001	152 [33, 439]	92 [13, 269]	< 0.001
< 65	85 [14, 242]	21 [0, 97]	< 0.001	46 [3, 177]	21 [0, 97]	< 0.001
< 60	23 [0, 89]	1 [0, 26]	< 0.001	9 [0, 57]	1 [0, 26]	< 0.001
< 55	3 [0, 30]	0 [0, 4]	< 0.001	0 [0, 14]	0 [0, 4]	< 0.001

(*Continued*)

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Table 2. (Continued)

Exposures	MINS (n = 1,760)	Non-MINS (n = 55,555)	*P* Values*	AKI (n = 3,215)	Non-AKI (n = 54,100)	*P* Values*
AUC under % MAP decrease from baseline, % * min						
< 10	1,449 [544, 3,015]	861 [318, 1,868]	< 0.001	1,275 [472, 2,692]	855 [315, 1,860]	< 0.001
< 15	850 [271, 1,970]	462 [134, 1,165]	< 0.001	719 [233, 1,718]	458 [132, 1,158]	< 0.001
< 20	437 [116, 1,146]	212 [39, 634]	< 0.001	356 [91, 998]	210 [39, 630]	< 0.001
< 25	199 [37, 597]	77 [5, 297]	< 0.001	151 [25, 507]	76 [5, 295]	< 0.001
< 30	80 [7, 271]	19 [0, 116]	< 0.001	51 [2, 226]	19 [0, 116]	< 0.001

Data are presented as mean ± SD, median [25th, 75th percentiles] or n (%).

*P values from chi-square test, Student's *t* test, or Wilcoxon rank sum test.

AKI = acute kidney injury; AUC = area under curve; MAP = mean arterial pressure; MINS = myocardial injury after noncardiac surgery; TWA = time-weighted average.

Determining MAP Thresholds. We first determined the absolute and relative (percent below baseline) thresholds below which MINS and AKI began to increase. Specifically, we assessed the relationships between MINS or AKI and the lowest MAP or the lowest percent decrease from baseline for a cumulative case total of 1, 3, 5, and 10 min, and time-weighted average under absolute thresholds (*i.e.*, less than 55, less than 60, less than 65, less than 70, less than 75 mmHg) or relative thresholds (i.e.,

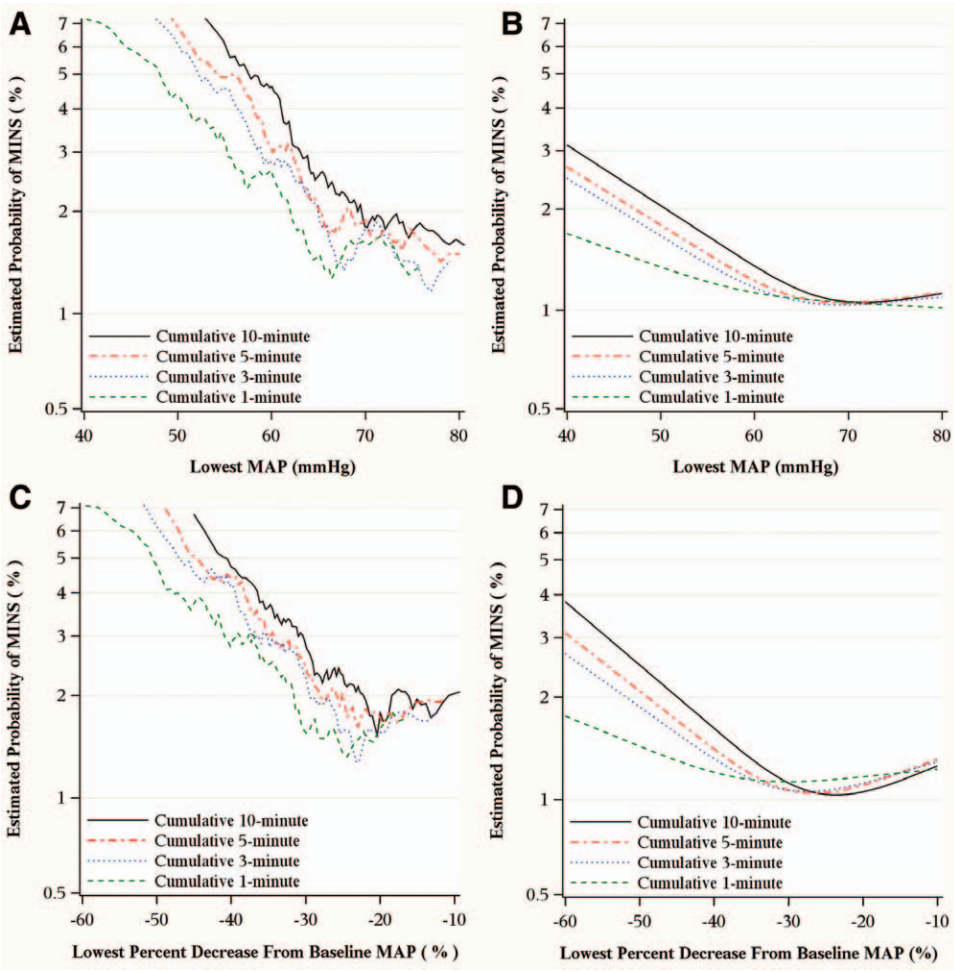

Fig. 2. Lowest mean arterial pressure (MAP) thresholds for myocardial injury after noncardiac surgery (MINS). Univariable and multivariable relationship between MINS and absolute and relative lowest MAP thresholds. (*A*) and (*C*) Estimated probability of MINS were from the univariable moving-window with the width of 10% data; (*B*) and (*D*) were from multivariable logistic regression smoothed by restricted cubic spline with three degrees and knots at 10th, 50th, and 90th percentiles of given exposure variable. Multivariable models adjusted for covariates in table 1. (*A*) and (*B*) show that there was a change point (*i.e.*, decreases steeply up and then flattens) around 65 mmHg, but 20% was not a change point from (*C*) and (*D*).

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greater than 10%, greater than 15%, greater than 20%, greater than 25%, greater than 30% decrease from baseline).

We first assessed the univariable relationship between each MAP threshold and MINS and AKI using moving-average smoothing plots. Relationships were then studied further using multivariable logistic regression to adjust for confounding and model the relationships; linearity between each MAP exposure and response was modeled by a restricted cubic spline function with three knots located at 10th, 50th, and 90th percentiles. The univariable moving-average plots and multivariable smoothed cubic spline curves were studied to find optimal thresholds based on the data. We further evaluated interactions between baseline MAP and the relationship between exposure and outcome.

Deriving MAP Exposures. Based on inspection of exposure *versus* outcome curves, we determined that absolute thresholds of 65 mmHg and lower and relative thresholds of 20% or more decrease from the baseline MAP were associated with the increased risk of both MINS and AKI. We then defined our main absolute and relative exposures to be (1) number of minutes under each threshold and (2) area under each threshold. Since all relationships were found to be nonlinear, we categorized patients as belonging to either a reference group who spent no time under a given threshold or to one of four groups based on quartiles of nonzero time spent under the threshold.

Specifically, we defined the absolute MAP reference group as patients whose intraoperative MAPs were never less than 65 mmHg. For the remaining patients, we counted the number of minutes within the lowest achieved category per patient: less than 50, 50 to 55, 55 to 60, and 60 to 65 mmHg. That is, each patient was assigned uniquely to one of the four hypotension categories. We then categorized cumulative minutes of exposure into 1, 2 to 4, or greater than equal to 5 min for a total of 12 groups (*i.e.*, four pressure ranges by three durations) and compared each to the reference group.

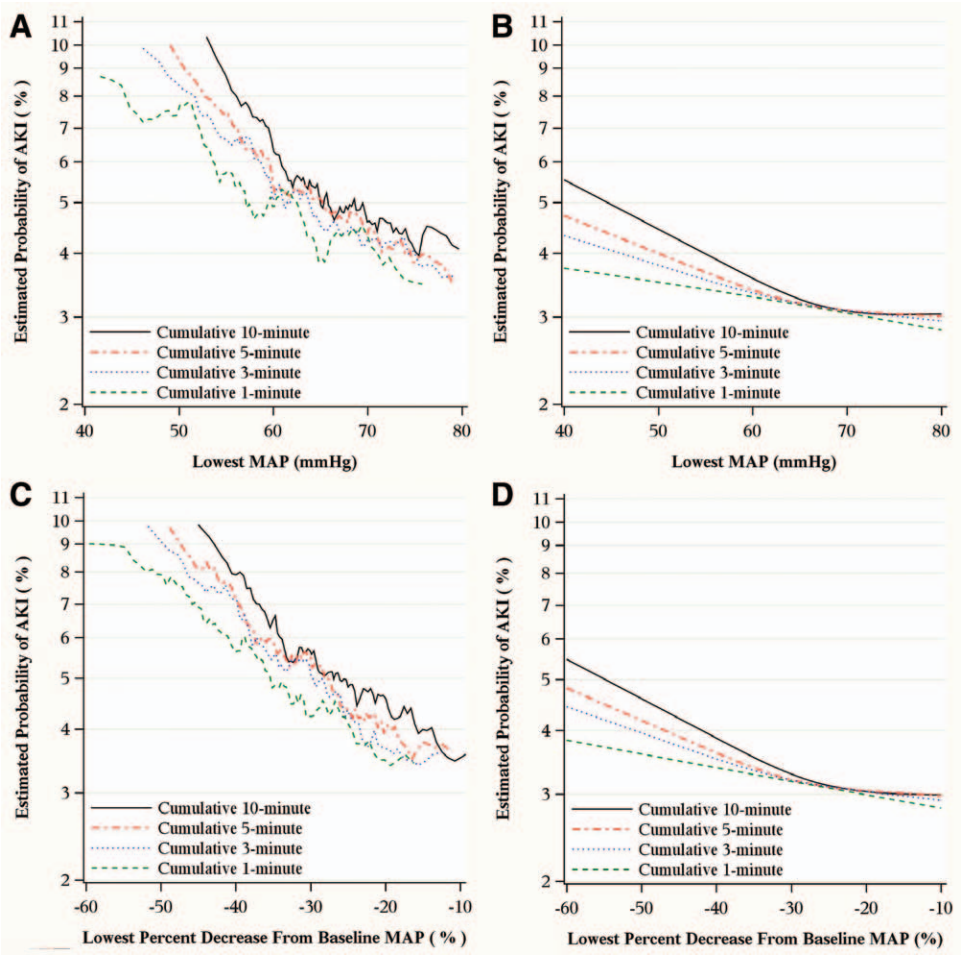

Fig. 3. The lowest mean arterial pressure (MAP) thresholds for acute kidney injury (AKI). Univariable and multivariable relationship between AKI and absolute and relative lowest MAP thresholds. (*A*) and (*C*) Estimated probability of AKI were from the univariable moving-window with the width of 10% data; (*B*) and (*D*) were from multivariable logistic regression smoothed by restricted cubic spline with three degrees and knots at 10th, 50th, and 90th percentiles of given exposure variable. Multivariable models adjusted for covariates in table 1. (*A*) and (*B*) show that there was a change point (*i.e.*, decreases steeply up and then flattens) around 65 mmHg, but 20% was not a change point from (*C*) and (*D*).

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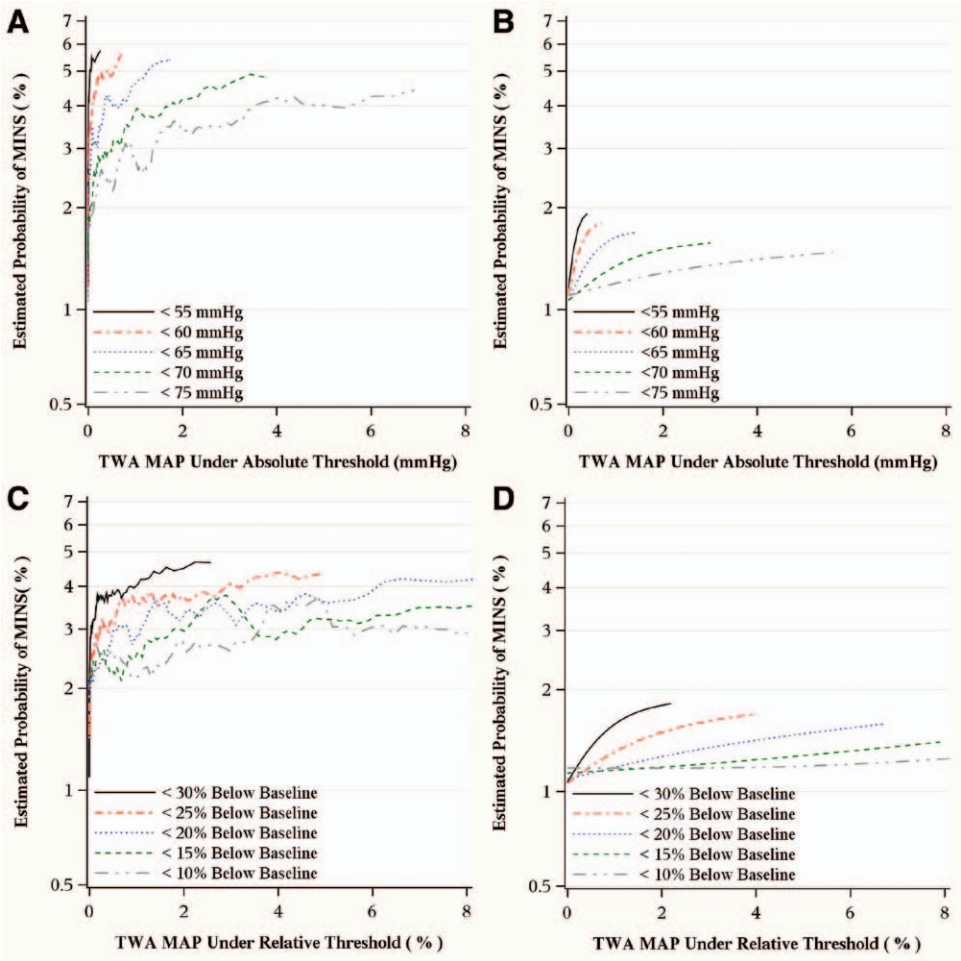

Fig. 4. Time-weighted average (TWA) mean arterial pressure (MAP) under absolute and relative thresholds for myocardial injury after noncardiac surgery (MINS). Univariable and multivariable relationship between MINS and TWA MAP under absolute and relative thresholds. (*A*) and (*C*) Estimated probability of MINS were from the univariable moving-window with the width of 10% data; (*B*) and (*D*) were from multivariable logistic regression smoothed by restricted cubic spline with three degrees and knots at 10th, 50th, and 90th percentiles of given exposure variable. Multivariable models adjusted for covariates in table 1. (*A*) and (*B*) show that MAP less than 65 mmHg was a change point since the risk of MINS was starting to increase more compared to the thresholds of 70 and 75 mmHg, but 20% was not a change point from (*C*) and (*D*).

We similarly defined the relative MAP reference group as patients whose intraoperative MAPs were never more than 20% below the preoperative reference pressure. For the remaining patients, we counted the number of minutes within the lowest achieved category per patient: 20 to 30%, 30 to 40%, 40 to 50%, and greater than 50% below baseline. Thus, each patient was again assigned uniquely to one of 12 groups (*i.e.*, four pressure ranges by three durations) and compared each to the reference group.

Multivariable logistic regression was used to assess the association between the above MAP exposures and postoperative MINS or AKI. All potentially confounding variables listed in table 1 were forced into the models regardless of statistical significance. Bonferroni correction was used to adjust for four main comparisons within each exposure of interest, with $P < 0.0125$ (*i.e.*, $P < 0.05/4 = 0.0125$) considered statistically significant. Interactions between baseline MAP and exposures were considered significant if $P < 0.05$. All analyses were performed with the use of SAS software, version 9.4 (SAS Institute, USA).

Sample Size Considerations. We expected to have between 50,000 and 150,000 patients meeting all study criteria. With at least 50,000 patients and the incidence of MINS or AKI of 2% or more, we had good statistical power (80% or more) to detect moderately small odds ratios, especially given the continuous/ordinal nature of the predictor variables.

Results

Of 164,514 patients having noncardiac surgery between 2005 and 2015, analysis included 57,315 patients who met our inclusion and exclusion criteria (fig. 1). Different subsets of these patients were included in studies by Walsh *et al.*[8] and Mascha *et al.*[16] The overall incidence of MINS was 3.1% and of AKI was 5.6% among qualified patients. Only 8,558

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patients (15%) had postoperative troponin tests, and we assumed that patients without the test did not have MINS.

Nearly all demographic, medical history, procedural, medicine, preoperative, and intraoperative factors were associated with both MINS and AKI (table 1). Descriptive statistics for baseline MAP and all MAP exposures are displayed in table A1. Baseline MAP was based on a mean of 5 ± 3 values per patient in the 6 months before surgery. Average baseline MAP was 93 ± 10 mmHg; preinduction MAP averaged 101 ± 16 mmHg, and intraoperative time-weighted average MAP was 84 ± 10 mmHg.

Univariable analyses showed that patients having postoperative MINS or AKI had higher time-weighted average, area under threshold, and number of minutes under all thresholds compared to those with no evidence of AKI or MINS (all $P < 0.001$; table 2).

Univariable moving-average and multivariable spline smoothing plots for the lowest observed MAPs for a patient are shown for MINS in fig. 2 and for AKI in fig. 3. Odds for both MINS and AKI increased for decreasing thresholds of MAP less than 65 mmHg for any of 1, 3, 5, or 10 min. A relative MAP threshold of 20% below baseline was not an obvious change-point for AKI (fig. 3), but it was for MINS (fig. 2). We thus selected an absolute reference threshold of 65 mmHg and a relative reference threshold of 20% below baseline for further analysis.

Increasing time-weighted average MAP under various absolute and relative thresholds was associated with increased odds of MINS (fig. 4) and AKI (fig. 5), both univariably and multivariably. Further, the relationships strengthened at lower thresholds. For example, the observed slope for less than 60 mmHg is steeper than that for less than 65 mmHg, and the

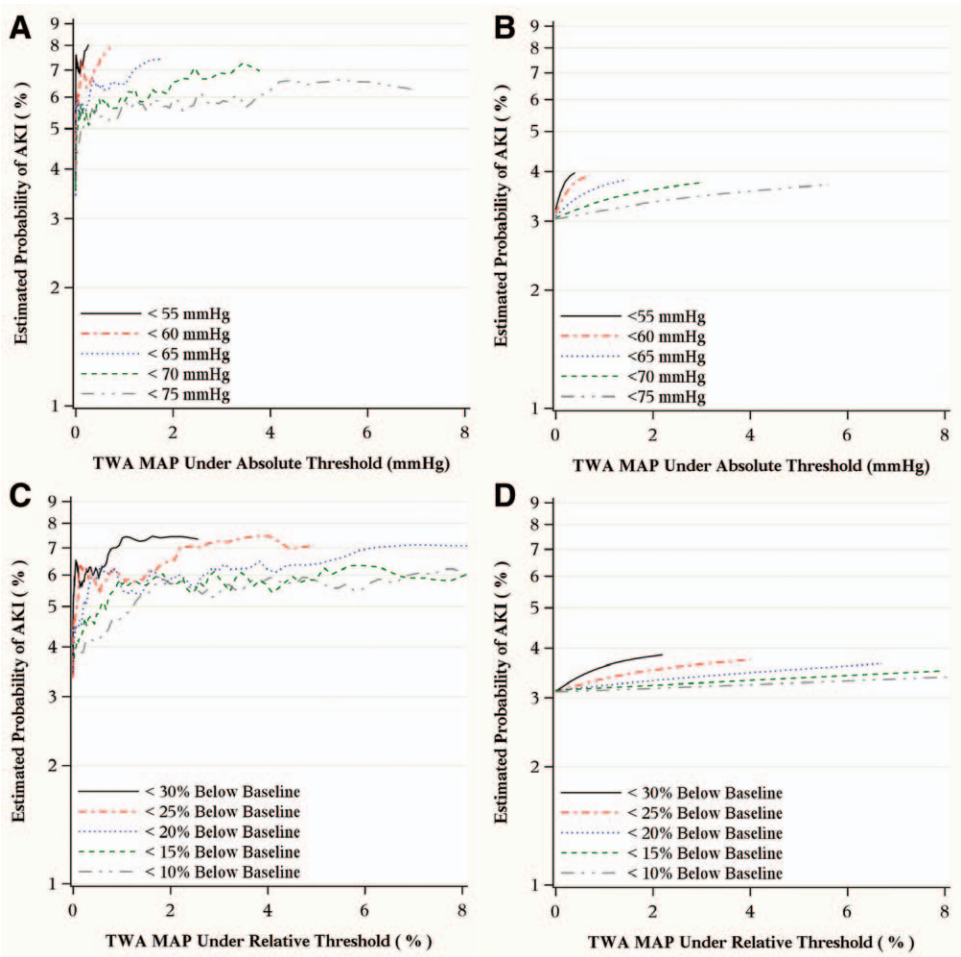

Fig. 5. Time-weighted average (TWA) mean arterial pressure (MAP) under absolute and relative thresholds for acute kidney injury (AKI). Univariable and multivariable relationship between AKI and TWA MAP under absolute and relative thresholds. (*A*) and (*C*) Estimated probability of AKI were from the univariable moving-window with the width of 10% data; (*B*) and (*D*) were from multivariable logistic regression smoothed by restricted cubic spline with three degrees and knots at 10th, 50th, and 90th percentiles of given exposure variable. Multivariable models adjusted for covariates in table 1. (*A*) and (*B*) show that MAP less than 65 mmHg was a change point since the risk of AKI was starting to increase more compared to the thresholds of 70 and 75 mmHg, but 20% was not a change point from (*C*) and (*D*).

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Table 3. Interaction *P* Values between Baseline MAP and Postoperative AKI and MINS*

Exposure	MINS	AKI
Lowest MAP for cumulative minutes		
≥ 1	0.19	0.94
≥ 3	0.012	0.99
≥ 5	0.001	0.64
≥ 10	< 0.001	0.38
Lowest % MAP decrease for cumulative minutes		
≥ 1	0.52	0.50
≥ 3	0.92	0.42
≥ 5	0.84	0.23
≥ 10	0.66	0.10
TWA under MAP, mmHg		
< 75	0.012	0.80
< 70	0.029	0.66
< 65	0.048	0.48
< 60	0.10	0.70
< 55	0.083	0.95
TWA under % MAP decrease from baseline		
< 10	0.67	0.38
< 15	0.64	0.53
< 20	0.69	0.68
< 25	0.93	0.72
< 30	0.91	0.52

*P values from multivariable logistic regression adjusting for covariates listed in table 1.

AKI = acute kidney injury; MAP = mean arterial pressure; MINS = myocardial injury after noncardiac surgery; TWA = time-weighted average.

observed slope for less than 25% below baseline is steeper than that for pressures less than 20% below baseline (figs. 4 and 5).

There was no interaction between baseline MAP and the relationship between the TWA under various relative thresholds for either MINS or AKI. Furthermore, there was no interaction with TWA under absolute thresholds for AKI (all $P > 0.40$). There was some evidence of interaction between baseline MAP and the relationship between TWA under absolute thresholds and MINS (table 3). Investigating further, univariable moving-average and multivariable spline smoothing plots by quartile of baseline MAP showed that there were no clinically important interactions at MAPs less than 65 mmHg (fig. 6).

Discriminative Ability

Using different absolute or relative thresholds did not increase discriminative ability, as evidenced by similar C-statistic values. The full multivariable model for MINS (table A2), including all baseline and intraoperative covariables mentioned in table 1, has a C statistic of 0.86. In contrast, blood pressure alone had a C statistic between 0.55 and 0.66. Whether hypotension exposure was defined by cumulative minutes of the lowest MAP (0.62 to 0.65) or duration under various thresholds (0.55 to 0.62), the C statistic values were essentially the same for absolute and relative exposures. There was thus no advantage to using relative thresholds for myocardial injury.

For AKI, the full multivariable model, including all baseline and intraoperative covariables mentioned in table 1, had a C statistic of 0.81 (table A3). In contrast, blood pressure alone had a C statistic between 0.54 and 0.59. Whether hypotension exposure was defined by cumulative minutes of lowest MAP or duration under various thresholds, the C statistic was nearly identical for absolute and relative thresholds. There was thus no advantage to using relative thresholds for AKI either.

Relationship between Exposure Categories and Outcomes

Time spent under the absolute threshold of MAP less than 65 mmHg had increased odds of MINS, with an odds ratio (OR; 98.75% CI) of 1.34 (1.06 to 1.68) for the third quartile and 1.60 (1.28 to 2.01) for the fourth quartile (table 4). Results were similar when hypotension exposure was characterized by area (rather than minutes) under absolute thresholds. In contrast, there were no significant associations between minutes or area under the relative threshold of 20% below baseline and MINS. Hypotension exposure was also characterized by various blood pressure ranges and exposure durations within each range. For instance, MAP less than 50 mmHg for at least 1 min or a 50% decrease from baseline for at least 1 min increased the odds of MINS after Bonferroni correction.

Time spent under the absolute threshold of MAP less than 65 mmHg had increased odds of AKI compared to patients never going less than 65 mmHg, with an OR (98.75% CI) of 1.20 (1.02 to 1.40) for the third quartile and 1.35 (1.14 to 1.58) for the fourth quartile (table 5). When hypotension exposure was characterized by area (rather than time) under absolute thresholds, odds were higher than reference only for the fourth quartile, with OR (98.75% CI) of 1.34 (1.15 to 1.58). For a relative threshold of 20% below baseline, again the fourth quartile had significantly higher odds of AKI with OR (98.75% CI) of 1.27 (1.01 to 1.61). The lowest hypotension exposure was also characterized by various blood pressure ranges and by exposure durations within each range. For instance, absolute categories of 50 to 55 mmHg for at least 1 min and less than 50 mmHg had higher odds of AKI compared to those never less than 65 mmHg. A relative decrease of greater than 50% from baseline MAP had higher odds of AKI compared to those never reaching less than 20% of baseline.

Discussion

We first characterized hypotension exposure by the lowest MAP maintained for various durations and by time under various *absolute* MAP thresholds. MAP less than 65 mmHg for greater than equal to 13 min (characterizing 50% of the patients who ever went less than 65 mmHg) was associated with significantly higher odds of myocardial and kidney injury. Injury was more common at lower absolute thresholds, and when hypotension was prolonged. At a MAP of 50 mmHg, for example, just 1 min significantly increased the risk for both myocardial and kidney injury.

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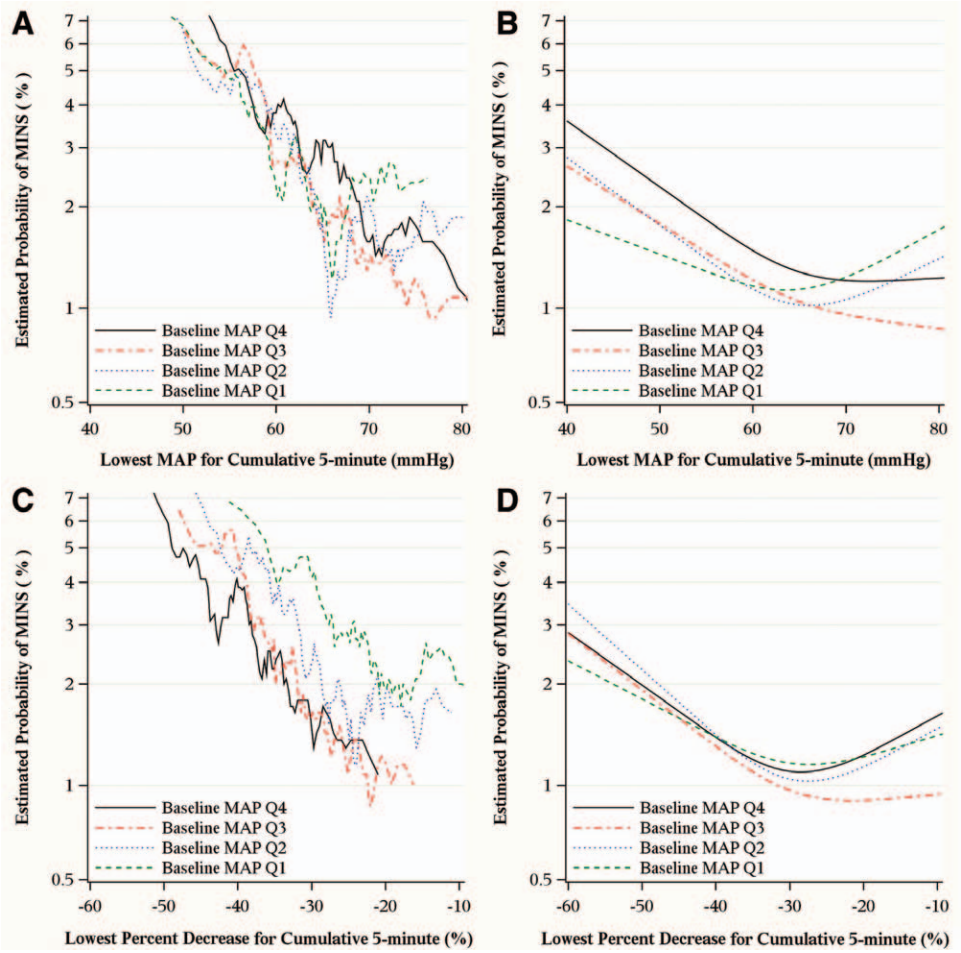

Fig. 6. Interaction between effects on myocardial injury after noncardiac surgery (MINS). (*A*) and (*C*) Estimated probability of MINS were from the univariable moving-window with the width of 10% data; (*B*) and (*D*) were from multivariable logistic regression smoothed by restricted cubic spline with three degrees and knots at 10th, 50th, and 90th percentiles of given exposure variable. Multivariable models adjusted for covariates in table 1. The interaction *P* values between the lowest mean arterial pressure (MAP) and baseline were < 0.001 and 0.84 between the lowest % MAP decrease and baseline, respectively. However, (*A*) and (*B*) plots show that there were no strong interaction effects as long as MAP is less than 65 mmHg.

Our results are broadly consistent with the results of previous reports. Based on previous studies, MAP less than absolute thresholds of 49 to 60 for various durations ranging from 1 to 30 min increases the risk of myocardial and kidney injury and mortality.[8–10,15,16] Available analyses thus suggest that even short periods of hypotension below MAPs thresholds of 50 to 65 mmHg are associated with kidney and myocardial injury. While causality cannot be determined from analysis of purely observational data, all results suggest that anesthesiologists should avoid unnecessary hypotension. In this context, it is sobering that therapeutic hypotension was used for decades—often for nonessential reasons.

We also characterized hypotension exposure by time under various *relative* MAP thresholds. Injury was more common at lower absolute thresholds, and when hypotension was prolonged. For example, a cumulative time exceeding 90 min (highest quartile of patients) with MAP less than 20% below preoperative values was needed to increase the odds of kidney injury, and total minutes less than 20% was not significant for myocardial injury. When MAP was more than 50% below preoperative values, just 5 min significantly increased the risk for both myocardial and kidney injury.

Again, our results are broadly consistent with the results of previous reports. Monk *et al.*[9] showed that blood pressure measurements less than 50% below baseline was associated with increased 30-day mortality although their analysis was limited in that one third of their patients lacked baseline blood pressures. Van Waes *et al.*[15] showed that a relative decrease in MAP to values less than 40% below preinduction blood pressure for more than 30 min was associated with the increased incidence of myocardial injury. Available analyses thus suggest that sufficient time with pressures less than 20% or even short periods of hypotension to less than 40 to 50% below preoperative MAPs are associated with kidney and myocardial injury. The classical teaching that intraoperative pressures should be maintained within 20% of preoperative values thus appears justified.

The interaction between preoperative blood pressure and the relationship between intraoperative blood pressure and

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Table 4. MINS: Multivariable Association with Absolute and Relative MAP Thresholds

Threshold	Total (n = 57,315)	MINS (n = 1,760)	Adjusted OR (98.75% CI)*	*P* Values*
Time under MAP < 65 mmHg				< 0.001
Reference (never < 65 mmHg)	16,230	247 (1.5%)	Ref = 1	
Q1 (1–5 min)	11,714	275 (2.3%)	1.01 (0.80–1.27)	0.93
Q2 (6–12 min)	9,442	270 (2.9%)	1.15 (0.90–1.45)	0.15
Q3 (13–28 min)	9,974	375 (3.8%)	1.34 (1.06–1.68)	0.0015†
Q4 (> 28 min)	9,955	593 (6.0%)	1.60 (1.28–2.01)	< 0.001†
Time > 20% decrease from baseline				0.046
Reference (never <20%)	6,112	123 (2.0%)	Ref = 1	
Q1 (1–16 min)	13,445	303 (2.3%)	0.82 (0.62–1.10)	0.10
Q2 (17–41 min)	12,502	310 (2.5%)	0.87 (0.64–1.17)	0.24
Q3 (42–90 min)	12,540	400 (3.2%)	0.96 (0.71–1.29)	0.72
Q4 (> 90 min)	12,716	624 (4.9%)	1.05 (0.76–1.45)	0.69
AUC for MAP under 65 mmHg				< 0.001
Reference(never < 65 mmHg)	16,230	247 (1.5%)	Ref = 1	
Q1 (1–16 mmHg · min)	10,355	216 (2.1%)	0.97 (0.76–1.25)	0.78
Q2 (17–41 mmHg · min)	10,251	292 (2.8%)	1.14 (0.90–1.44)	0.17
Q3 (42–90 mmHg · min)	10,239	379 (3.7%)	1.30 (1.04–1.63)	0.0035†
Q4 (> 91 mmHg · min)	10,240	626 (6.1%)	1.62 (1.30–2.02)	< 0.001†
AUC under % MAP decrease from baseline < 20%				< 0.001
Reference (never <20%)	6,112	123 (2.0%)	Ref = 1	
Q1 (1–83 % · min)	12,880	256 (2.0%)	0.78 (0.58–1.06)	0.042
Q2 (84–275 % · min)	12,733	328 (2.6%)	0.88 (0.66–1.19)	0.30
Q3 (276–728 % · min)	12,800	407 (3.2%)	0.97 (0.72–1.31)	0.79
Q4 (> 728 % · min)	12,790	646 (5.1%)	1.19 (0.87–1.64)	0.16
Time in the lowest MAP categories				< 0.001
Reference (never < 65 mmHg)	16,230	247 (1.5%)	Ref = 1	
60–65 mmHg			0.99 (0.78–1.28)	0.97
1 min	2,799	52 (1.9%)	0.95 (0.64–1.43)	0.77
2–4 min	3,859	81 (2.1%)	0.92 (0.66–1.30)	0.56
> 4 min	3,983	84 (2.1%)	1.11 (0.79–1.55)	0.44
55–60 mmHg			1.07 (0.85–1.35)	0.48
1 min	4,067	99 (2.4%)	1.06 (0.77–1.46)	0.64
2–4 min	4,393	131 (3.0%)	1.11 (0.83–1.50)	0.36
> 4 min	2,834	72 (2.5%)	1.01 (0.70–1.45)	0.94
50–55 mmHg			1.26 (0.99–1.59)	0.015
1 min	4,053	147 (3.6%)	1.35 (1.02–1.80)	0.008
2–4 min	3,308	138 (4.2%)	1.28 (0.96–1.72)	0.035
> 4 min	1,376	46 (3.3%)	0.98 (0.63–1.53)	0.91
< 50 mmHg			1.68 (1.35–2.08)	< 0.001†
1 min	3,607	173 (4.8%)	1.49 (1.13–1.96)	< 0.001
2–4 min	4,150	254 (6.1%)	1.63 (1.26–2.10)	< 0.001
> 4 min	2,656	236 (8.9%)	1.97 (1.50–2.59)	< 0.001
Time in the lowest % MAP decrease categories				< 0.001
Reference (never < 20%)	6,112	123 (2.0%)	Ref = 1	
20–30% decrease			0.70 (0.51–0.96)	0.0045†
1 min	1,354	36 (2.7%)	1.24 (0.74–2.08)	0. 30
2–4 min	2,418	43 (1.8%)	0.74 (0.46–1.19)	0.12
> 4 min	8,517	109 (1.3%)	0.61 (0.43–0.87)	< 0.001
30–40% decrease			0.87 (0.65–1.16)	0.22
1 min	3,226	68 (2.1%)	0.73 (0.49–1.10)	0.058
2–4 min	4,898	140 (2.9%)	0.93 (0.66–1.31)	0.61
> 4 min	9,935	251 (2.5%)	0.92 (0.67–1.25)	0.49
> 40% decrease			0.99 (0.74–1.34)	0.97
1 min	3,977	118 (3.0%)	0.89 (0.62–1.28)	0.44
2–4 min	4,816	200 (4.2%)	1.07 (0.77–1.49)	0.61
> 4 min	4,792	183 (3.8%)	1.09 (0.77–1.55)	0.52
> 50% decrease			1.46 (1.07–1.99)	0.0021†
1 min	2,644	145 (5.5%)	1.31 (0.92–1.88)	0.057
2–4 min	2,829	176 (6.2%)	1.34 (0.95–1.91)	0.036
> 4 min	1,797	168 (9.3%)	2.12 (1.45–3.09)	< 0.001

*Multivariable logistic model adjusting for covariates listed in table 1. Bonferroni correction was used to adjust for four comparisons within each exposure of interest. †$P < 0.05/4 = 0.0125$ was considered as statistically significant. For the detailed categories of minutes below absolute and relative thresholds (1, 2–4, greater than 4 min), the significance criterion was 0.05/12 = 0.0042.

AUC = area under curve; MAP = mean arterial pressure; MINS = myocardial injury after noncardiac surgery; OR = odds ratio.

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Table 5. AKI: Multivariable Associations with Absolute and Relative MAP Thresholds

Threshold	Total (n = 57,315)	AKI (n = 3,870)	Adjusted OR (98.75% CI)*	*P* Values*
Time under MAP < 65 mmHg				< 0.001
Reference (never < 65 mmHg)	16,230	658 (4.1%)	Ref = 1	
Q1 (1–5 min)	11,714	570 (4.9%)	1.04 (0.89–1.22)	0.49
Q2 (6–12 min)	9,442	520 (5.5%)	1.15 (0.98–1.35)	0.032
Q3 (13–28 min)	9,974	597 (6.0%)	1.20 (1.02–1.40)	0.0049†
Q4 (> 28 min)	9,955	870 (8.7%)	1.35 (1.14–1.58)	< 0.001†
Time > 20% decrease from baseline				0.13
Reference (never <20%)	6,112	210 (3.4%)	Ref = 1	
Q1 (1–16 min)	13,445	612 (4.6%)	1.12 (0.90–1.38)	0.19
Q2 (17–41 min)	12,502	636 (5.1%)	1.15 (0.93–1.43)	0.10
Q3 (42–90 min)	12,540	729 (5.8%)	1.18 (0.95–1.47)	0.058
Q4 (> 90 min)	12,716	1,028 (8.1%)	1.27 (1.01–1.61)	0.010†
AUC under 65 mmHg				< 0.001
Reference(never < 65 mmHg)	16,230	658 (4.1%)	Ref = 1	
Q1 (1–16 mmHg * min)	10,355	517 (5.0%)	1.11 (0.95–1.30)	0.1051
Q2 (17–41 mmHg * min)	10,251	548 (5.3%)	1.12 (0.95–1.31)	0.086
Q3 (42–90 mmHg * min)	10,239	588 (5.7%)	1.13 (0.96–1.32)	0.064
Q4 (> 91 mmHg * min)	10,240	904 (8.8%)	1.34 (1.15–1.58)	< 0.001†
AUC under % MAP decrease from baseline < 20%				0.0021
Reference (never <20%)	6,112	210 (3.4%)	Ref = 1	
Q1 (1–83 % · min)	12,880	561 (4.4%)	1.10 (0.89–1.37)	0.26
Q2 (84–275 % · min)	12,733	676 (5.3%)	1.21 (0.97–1.50)	0.029
Q3 (276–728 % · min)	12,800	707 (5.5%)	1.12 (0.89–1.39)	0.21
Q4 (> 728 % · min)	12,790	1,061 (8.3%)	1.35 (1.07–1.70)	0.0013†
Time in the lowest MAP categories				< 0.001
Reference (never < 65 mmHg)	16,230	658 (4.1%)	Ref = 1	
60–65 mmHg			1.13 (0.96–1.32)	0.061
1 min	2,799	129 (4.6%)	1.05 (0.81–1.36)	0.62
2–4 min	3,859	209 (5.4%)	1.20 (0.97–1.49)	0.031
> 4 min	3,983	186 (4.7%)	1.11 (0.88–1.39)	0.26
55–60 mmHg			1.05 (0.90–1.23)	0.41
1 min	4,067	175 (4.3%)	0.89 (0.71–1.12)	0.23
2–4 min	4,393	243 (5.5%)	1.11 (0.90–1.36)	0.23
> 4 min	2,834	163 (5.8%)	1.22 (0.96–1.56)	0.039
50–55 mmHg			1.29 (1.10–1.51)	< 0.001†
1 min	4,053	254 (6.3%)	1.25 (1.02–1.54)	0.0061
2–4 min	3,308	237 (7.2%)	1.29 (1.04–1.61)	0.0029
> 4 min	1,376	108 (7.8%)	1.43 (1.06–1.92)	0.0031
< 50 mmHg			1.23 (1.05–1.44)	0.0010†
1 min	3,607	229 (6.3%)	1.10 (0.89–1.37)	0.26
2–4 min	4,150	315 (7.6%)	1.23 (1.00–1.50)	0.011
> 4 min	2,656	309 (11.6%)	1.43 (1.15–1.78)	< 0.0001
Time in the lowest % MAP decrease categories				0.022
Reference (never <20%)	6,112	210 (3.4%)	Ref = 1	
20–30% decrease			1.09 (0.88–1.36)	0.32
1 min	1,354	51 (3.8%)	1.02 (0.67–1.53)	0.93
2–4 min	2,418	101 (4.2%)	1.15 (0.83–1.58)	0.28
> 4 min	8,517	356 (4.2%)	1.09 (0.87–1.38)	0.33
30–40% decrease			1.14 (0.92–1.40)	0.12
1 min	3,226	145 (4.5%)	1.06 (0.79–1.41)	0.63
2–4 min	4,898	270 (5.5%)	1.23 (0.96–1.59)	0.036
> 4 min	9,935	519 (5.2%)	1.14 (0.91–1.43)	0.16
>40% decrease			1.24 (0.99–1.54)	0.015
1 min	3,977	236 (5.9%)	1.22 (0.94–1.59)	0.056
2–4 min	4,816	323 (6.7%)	1.20 (0.93–1.54)	0.078
> 4 min	4,792	363 (7.6%)	1.34 (1.04–1.73)	0.0042
> 50% decrease			1.35 (1.07–1.72)	0.0015†
1 min	2,644	200 (7.6%)	1.32 (0.99–1.76)	0.014
2–4 min	2,829	236 (8.3%)	1.26 (0.95–1.67)	0.043
> 4 min	1,797	205 (11.4%)	1.62 (1.19–2.20)	< 0.0001

*Multivariable logistic model adjusting for covariates listed in table 1. Bonferroni correction was used to adjust for four comparisons within each exposure of interest. †$P < 0.05/4 = 0.0125$ was considered as statistical significant. For the detailed categories of minutes below absolute and relative thresholds (1, 2–4, greater than 4 min), the significance criterion was 0.05/12 = 0.0042.

AKI = acute kidney injury; AUC = area under curve; MAP = mean arterial pressure, OR = odds ratio.

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postoperative outcome was evaluated by Levin *et al.*[21] They found that hypertensive patients had more intraoperative blood pressure lability and that lability decreased mortality. In our study, however, there was no interaction between baseline pressure and the relationship between intraoperative hypotension and AKI. Intraoperative hypotension was thus proportionately related to AKI over the entire range of preoperative pressures.

In contrast, there was a significant interaction between baseline pressure and the relationship between intraoperative pressure and myocardial injury. However, the interaction was only substantive at intraoperative MAPs exceeding 65 mmHg. In the clinically relevant range of hypotensive pressures less than 65 mmHg, there was no important interaction. Preoperative blood pressure thus had no important effect on the relationship between intraoperative hypotension and myocardial injury.

From a clinical perspective, our interaction analysis thus indicates that anesthesiologists can manage intraoperative blood pressure without reference to preoperative values—a conclusion that differs starkly from classical anesthesia teaching that patients with high preoperative pressures should be maintained at relatively high pressures throughout surgery. A caveat, of course, is that we evaluated only two organs. It remains possible that preoperative pressures do matter for the brain and other physiologic functions such as gut permeability.

A novel aspect of our study is comparison between absolute and relative thresholds. Both were predictive. However, there was no advantage to using relative over absolute thresholds for AKI or myocardial injury. Absolute thresholds are easier to use since a reliable baseline pressure is not required. Furthermore, absolute thresholds are far easier to incorporate into decision support systems that would not normally have access to individual preoperative reference values. Therefore, we conclude that clinicians can use absolute thresholds to guide intraoperative blood pressure management.

We defined myocardial injury on the basis of increased cardiac enzymes. However, cardiac enzymes were not routinely measured even in relatively high-risk patients during the study period. Consequently, our analysis was mostly based on clinically apparent myocardial infarctions, thus underestimating the actual incidence of myocardial injury by about a factor-of-three.[1] Whether the relationships between hypotension and myocardial injury that we report apply comparably to silent injury remains unknown. However, the physiology is probably similar, suggesting that the relationships are probably similar.

As in any retrospective analysis, confounding and bias are concerns. For example, patients who experienced MINS or AKI were generally sicker and had more preoperative comorbidities. However, our large sample size and detailed registry allowed us to statistically adjust for many potential confounding factors. Our results are nonetheless surely somewhat degraded by both unknown and known but poorly characterized confounders. The extent to which either contributes is hard to assess.

About 60% of our patients had blood pressure measured oscillometrically at 1- to 5-min intervals. We linearly interpolated between measurements to provide reasonable estimates of intervening values, but is obviously less accurate than values from arterial catheters that were available at 1-min intervals. It seems unlikely that more frequent measurements would much change the harm thresholds we identified.

Conclusion

Pressures that until recently were considered clinically acceptable, for instance, a MAP of 65 mmHg, were associated with both myocardial and renal injuries. At lower pressures, the association was stronger and only brief exposures were required. Associations based on relative thresholds were no stronger than those based on absolute thresholds. Furthermore, there was no clinically important interaction with preoperative pressure. The extent to which the associations we observe are causal remains to be determined. But to the extent that they are, a strategy aimed at maintaining MAP above 65 mmHg appears to be as good as one based on the percentage reduction from baseline. This result is fortuitous because absolute thresholds are easier to use in that they do not require a reliable baseline pressure and can thus more easily be incorporated into decision support systems. While retrospective analyses cannot assess causality, our results suggest that maintaining intraoperative MAP greater than 65 mmHg may reduce the risk of AKI and myocardial injury—the leading cause of 30-day postoperative mortality.

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Competing Interests

The authors declare no competing interests.

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Appendix

Table A1. Summarized Statistics of MAP

Exposures	Mean ± SD	Median [Q1, Q3]	P10–P90
No. of baseline MAP reading	5 ± 3	4 [3, 6]	2–9
Baseline MAP	93 ± 10	93 [86, 99]	81–105
Preinduction MAP	101 ± 16	100 [90, 111]	82–122
TWA-MAP	84 ± 10	83 [77, 90]	72–97
Lowest MAP, mmHg, for cumulative minutes			
≥ 1	59 ± 11	59 [52, 66]	45–72
≥ 3	63 ± 10	63 [57, 69]	51–76
≥ 5	65 ± 9	64 [59, 70]	54–77
≥ 10	67 ± 9	67 [61, 73]	57–79
Lowest MAP, mmHg, for sustained minutes			
≥ 1	59 ± 11	59 [52, 66]	45–72
≥ 3	65 ± 9	64 [59, 70]	54–76
≥ 5	67 ± 9	67 [61, 72]	57–78
≥ 10	71 ± 9	71 [66, 77]	61–83
Lowest % MAP decrease from baseline (%) for cumulative minutes			
≥ 1	36 ± 13	36 [45, 28]	52–20
≥ 3	31 ± 12	32 [39, 24]	46–16
≥ 5	30 ± 12	30 [38, 22]	44–15
≥ 10	27 ± 11	27 [34, 20]	40–12
Lowest % MAP decrease from baseline for sustained minutes			
≥ 1	36 ± 13	36 [45, 28]	52–20
≥ 3	29 ± 12	30 [37, 22]	44–15
≥ 5	27 ± 11	27 [34, 20]	41–13
≥ 10	22 ± 11	23 [30, 15]	36–8
Minutes of MAP under absolute threshold, mmHg			
< 75	65 ± 76	41 [15, 87]	3–152
< 70	37 ± 53	19 [4, 47]	0–93
< 65	17 ± 32	6 [0, 20]	0–44
< 60	6 ± 16	1 [0, 6]	0–17
< 55	2 ± 7	0 [0, 2]	0–6
< 50	1 ± 3	0 [0, 0]	0–2
Minutes of % MAP decrease under relative threshold			
< 20	60 ± 76	33 [9,82]	0–150
< 30	20 ± 39	5 [0,21]	0–55
< 40	4 ± 13	0 [0,2]	0–10
< 50	1 ± 3	0 [0,0]	0–1
TWA of MAP, mmHg			
< 75	2.2 ± 2.5	1.3 [0.4, 3.1]	0–5.4
< 70	1.0 ± 1.5	0.5 [0.1, 1.3]	0–2.8
< 65	0.4 ± 0.8	0.1 [0.0, 0.5]	0–1.2
< 60	0.2 ± 0.4	0.0 [0.0, 0.1]	0–0.4
< 55	0.1 ± 0.2	0.0 [0.0, 0.0]	0–0.1
TWA of % MAP decrease from baseline, mmHg			
< 10	6.2 ± 5.6	4.6 [1.8, 9.2]	0.5–14.1
< 15	3.9 ± 4.3	2.4 [0.7, 5.8]	0.1–9.9
< 20	2.3 ± 3.1	1.1 [0.2, 3.1]	0–6.3
< 25	1.2 ± 2.0	0.4 [0.0, 1.5]	0–3.4
< 30	0.6 ± 1.2	0.1 [0.0, 0.6]	0–1.6
AUC of MAP, mmHg * min			
< 75	498 ± 722	262 [75, 630]	6–1,211
< 70	234 ± 414	94 [14, 276]	0–595
< 65	94 ± 211	22 [0, 101]	0–249
< 60	34 ± 98	1 [0, 28]	0–92
< 55	12 ± 44	0 [0, 4]	0–30
AUC of % MAP decrease from baseline, % * min			
< 10	1,421 ± 1,701	875 [323, 1,897]	76–3,265
< 15	904 ± 1,251	471 [137, 1,185]	15–2,198
< 20	526 ± 860	217 [41, 647]	0–1,340
< 25	275 ± 545	79 [6, 305]	0–720
< 30	129 ± 316	20 [0, 121]	0–335

AUC = area under curve; MAP = mean arterial pressure; TWA = time-weighted average.

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Table A2. Multivariable Associations between Myocardial Injury after Noncardiac Surgery and Risk Factors

Factor	*df*	Chi-square	*P* Values
Cumulative minutes under Intraoperative MAP < 65 mmHg	4	43.55	< 0.0001
Surgical procedure	38	217.05	< 0.0001
Age, yr	1	142.96	< 0.0001
Congestive heart failure	1	93.81	< 0.0001
ASA status	1	83.18	< 0.0001
Emergency	1	76.94	< 0.0001
Weight loss	1	60.24	< 0.0001
Coagulopthy	1	57.73	< 0.0001
Fluid and electrolyte disorders	1	47.15	< 0.0001
Surgical time*	1	44.85	< 0.0001
Use of arterial catheter	1	36.84	< 0.0001
Peripheral vascular disease	1	20.37	< 0.0001
Chronic blood loss anemia	1	16.88	< 0.0001
Paralysis	1	15.86	< 0.0001
Intraoperative blood loss*	1	12.35	0.0004
Female	1	8.89	0.0029
Hypertension	1	8.56	0.0034
Other neurologic disorders	1	7.61	0.0058
Obesity	1	7.39	0.0066
ACE inhibitor	1	6.94	0.0084
Pulmonary circulation disease	1	6.92	0.0085
Baseline MAP	1	5.66	0.0173
Preoperative hemoglobin	1	3.65	0.0560
Chronic pulmonary disease	1	3.60	0.0579
Liver disease	1	2.96	0.0855
Race	2	2.58	0.2756
Renal failure	1	1.74	0.1875
Drug abuse	1	1.69	0.1932
Hypothyroidism	1	1.60	0.2062
Valvular disease	1	1.36	0.2432
Diuretic	1	0.90	0.3435
β-blocker	1	0.59	0.4430
Deficiency anemias	1	0.51	0.4765
Psychoses	1	0.41	0.5209
Calcium channel blocker	1	0.39	0.5331
Baseline EGFR*	1	0.38	0.5369
Lymphoma	1	0.28	0.5991
Rheumatoid arthritis/collagen vas	1	0.23	0.6330
Alcohol abuse	1	0.21	0.6496
Depression	1	0.14	0.7042
Tumor	1	0.07	0.7935
Metastatic cancer	1	0.06	0.7989
Angiotensin receptor blockers	1	0.05	0.8174
Diabetes	1	0.00	0.9637

*Logarithmic-transformed in the multivariable logistic model.

ACE = angiotensin-converting enzyme; ASA = American Society of Anesthesiologists; *df* = degrees of freedom; EGFR = estimated glomerular filtration rate; MAP = mean arterial pressure.

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Table A3. Multivariable Associations between Acute Kidney Injury and Risk Factors

Factor	*df*	Chi-square	*P* Values
Cumulative minutes under Intraoperative MAP < 65 mmHg	4	24.89	< 0.0001
Surgical procedure	44	945.63	< 0.0001
Female	1	171.09	< 0.0001
Weight loss	1	151.85	< 0.0001
Preoperative hemoglobin	1	94.91	< 0.0001
Baseline MAP	1	86.51	< 0.0001
Coagulopthy	1	61.94	< 0.0001
ASA status	1	50.72	< 0.0001
Obesity	1	44.74	< 0.0001
Surgical time*	1	44.66	< 0.0001
Intraoperative blood loss*	1	43.04	< 0.0001
Congestive heart failure	1	41.59	< 0.0001
Fluid and electrolyte disorders	1	29.65	< 0.0001
Renal failure	1	27.19	< 0.0001
Race	2	21.06	< 0.0001
Diabetes	1	20.24	< 0.0001
Emergency	1	18.21	< 0.0001
Age, yr	1	10.79	0.0010
Angiotensin receptor blockers	1	9.72	0.0018
Hypertension	1	7.22	0.0072
Calcium channel blocker	1	6.41	0.011
Chronic pulmonary disease	1	3.19	0.074
Alcohol abuse	1	3.07	0.080
β-blocker	1	2.76	0.097
Diuretic	1	2.21	0.14
Hypothyroidism	1	2.21	0.14
Rheumatoid arthritis/collagen vas	1	2.20	0.14
Liver disease	1	1.94	0.16
Peripheral vascular disease	1	1.89	0.17
Use of arterial catheter	1	1.84	0.17
Chronic blood loss anemia	1	1.64	0.20
Valvular disease	1	1.09	0.30
Metastatic cancer	1	0.80	0.37
Baseline EGFR*	1	0.73	0.39
Lymphoma	1	0.57	0.45
Tumor	1	0.48	0.49
ACE inhibitor	1	0.43	0.51
Deficiency anemias	1	0.06	0.80
Paralysis	1	0.03	0.86
Pulmonary circulation disease	1	0.02	0.89
Psychoses	1	0.02	0.89
Depression	1	0.02	0.89
Other neurologic disorders	1	0.01	0.93
Drug abuse	1	0.00	0.96

*Logarithmic-transformed in the multivariable logistic model.

ACE = angiotensin-converting enzyme; ASA = American Society of Anesthesiologists; EGFR = estimated glomerular filtration rate; MAP = mean arterial pressure.

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The Effect of Implementation of Preoperative and Postoperative Care Elements of a Perioperative Surgical Home Model on Outcomes in Patients Undergoing Hip Arthroplasty or Knee Arthroplasty

Thomas R. Vetter, MD, MPH, Joydip Barman, PhD, MBA, James M. Hunter, Jr, MD, Keith A. Jones, MD, and Jean-Francois Pittet, MD

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BACKGROUND: The Perioperative Surgical Home (PSH) seeks to remedy the currently highly fragmented and expensive perioperative care in the United States. The 2 specific aims of this health services research study were to assess the association between the preoperative and postoperative elements of an initial PSH model and a set of (1) clinical, quality, and patient safety outcomes and (2) operational and financial outcomes, in patients undergoing total hip arthroplasty (THA) or total knee arthroplasty (TKA).

METHODS: A 2-group before-and-after study design, with a nonrandomized preintervention PSH (PRE-PSH group, N = 1225) and postintervention PSH (POST-PSH group, N = 1363) data-collection strategy, was applied in this retrospective observational study. The 2 study groups were derived from 2 sequential 24-month time periods. Conventional inferential statistical tests were applied to assess group differences and associations, including regression modeling.

RESULTS: Compared with the PRE-PSH group, there was a 7.2% (95% confidence interval [CI], 4.0%–10.4%, $P < .001$) increase in day of surgery on-time starts (adjusted odds ratio [aOR] 2.54; 95% CI, 1.70–3.80; $P < .001$); a 5.8% (95% CI, 3.1%–8.5%, $P < .001$) decrease in day of surgery anesthesia-related delays (aOR 0.66; 95% CI, 0.52–0.84, $P < .001$); and a 2.2% (95% CI, 0.5%–3.9%, $P = .011$) decrease in ICU admission rate (aOR 0.45; 95% CI, 0.31–0.66, $P < .001$) in the POST-PSH group. There was a 0.6 (95% CI, 0.5–0.7) decrease in the number of ICU days in the POST-PSH group compared with the PRE-PSH group ($P = .028$); however, there was no significant difference (0.1 day; 95% CI, −0.03 to 0.23) in the total hospital length of stay between the 2 study groups ($P = .14$). There was also no significant difference (1.2%; 95% CI, −0.6 to 3.0) in the all-cause readmission rate between the study groups ($P = .18$). Compared with the PRE-PSH group, the entire POST-PSH group was associated with a $432 (95% CI, 270–594) decrease in direct nonsurgery costs for the THA ($P < .001$) and a $601 (95% CI, 430–772) decrease in direct nonsurgery costs for the TKA ($P < .001$) patients.

CONCLUSIONS: On the basis of our preliminary findings, it appears that a PSH model with its expanded role of the anesthesiologist as the "perioperativist" can be associated with improvements in the operational outcomes of increased on-time surgery starts and reduced anesthesia-related delays and day-of-surgery case cancellations, and decreased selected costs in patients undergoing THA and TKA. (Anesth Analg 2017;124:1450–8)

The Perioperative Surgical Home (PSH) is a paradigm shift that seeks to remedy the currently highly fragmented and expensive perioperative care in the United States.[1,2] The PSH is a patient-centered approach to the surgical patient, with a strong emphasis on process standardization, evidence-based clinical care pathways, as well as robust coordination and integration of care. This new model of care guides the patient and their family members through the complexities of the perioperative continuum, especially during transitions of care, from the decision for surgery to the postdischarge phase.[3] As this new patient care model continues to be defined and implemented, there will likely be variants of the PSH, predicated on the local infrastructure, resources, internal/external forces, and the degree of collaboration among all of its institutional stakeholders.[1,4]

Furthermore, a successful PSH model will not be a static entity but will undergo continuous development, with an attendant expansion of scope and services. For example, at the University of Alabama at Birmingham (UAB), when we initiated our PSH model in October 2010, we initially focused on the preoperative phase of care. In October 2012, our PSH model was expanded to include the postoperative phase of care. This initial PSH model at UAB was predicated on an expanded role of the anesthesiologist as the "perioperativist."[3]

Clinical proof-of-concept has been defined as "[the] construction of working prototypes of the necessary functionality and infrastructure in sufficient quality to investigate evidence for improving health in daily use for a suitable period of time; a limited but relevant set of people [patients]

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serving as [study] subjects."[5] An initial, limited scale clinical proof-of-concept study could be undertaken appropriately at one's institutional level to determine the operational and fiscal viability of further development and deployment ("Go-No Go decision") of a novel yet nascent PSH model for the management of surgical patients.[4]

The 2 specific aims of this clinical proof-of-concept, health services research study were thus to assess the association between the dissemination and implementation of the preoperative and postoperative elements of the initial UAB PSH model and a subset of (1) clinical, quality, and patient safety outcomes; and (2) operational and financial outcomes, in patients undergoing total hip arthroplasty (THA) or total knee arthroplasty (TKA).

METHODS

This study was approved by the UAB institutional review board (IRB) (X141001007). This study was granted expedited status by the UAB IRB because the research involved materials (data, documents, records) collected solely for nonresearch purposes (such as medical treatment or diagnosis) and the research used quality assurance methodologies. This study per se also involved minimal additional risk to the study participants. A waiver of informed consent documentation and a waiver of authorization also were granted by the UAB IRB. This study was a retrospective, observational (before-and-after) care redesign study. It was not a prospective clinical trial. Thus, it was not registered.

Study Design

A 2-group before-and-after study design, with a nonrandomized, preintervention, and postintervention data collection strategy, was applied in this retrospective observational study.[6,7] This work thus adheres to the STROBE (Strengthening the Reporting of Observational studies in Epidemiology) reporting guidelines and associated checklist.[8,9]

Study Participants and Study Groups

Patients 19 years of age or older who underwent either a THA or a TKA at UAB Highlands Hospital, our 219-bed satellite facility and PSH venue, were eligible for inclusion in this study. The orthopedic joint surgery outpatient clinics also were located on the UAB Highlands Hospital campus.

Patients in the preintervention PSH (PRE-PSH) group and postintervention PSH (POST-PSH) group were identified by the use of our institutional claims database as those patients who were billed with a Current Procedural Terminology code for a THA or a TKA (Supplemental Digital Content, Appendix A, http://links.lww.com/AA/B576). This institutional claims database included every such patient who underwent a THA or TKA. During the 24-month PRE-PSH and 24-month POST-PSH epochs, there were no changes in the involved orthopedic surgeons and in their surgical techniques.

The 2 study groups were derived from 2 sequential 24-month time periods. To reduce selection bias, the PRE-PSH group consisted of all consecutive THA and TKA patients who underwent surgery in the 24-month period from October 1, 2008, to September 30, 2010. During this 24-month PRE-PSH epoch, patients were seen in a longstanding preadmission testing clinic, at which time a registered nurse essentially collected basic clinical information (history of present illness, review of systems, and anesthesia history), and widely variable laboratory tests, electrocardiogram, and chest radiographs were ordered. Patients with specific symptoms had additional diagnostic tests (eg, resting transthoracic echocardiogram) ordered, after discussion with an attending anesthesiologists working in the operating room that day. This preadmission testing clinic functioned as a simple preoperative screening clinic. During this 24-month PRE-PSH epoch, postoperative patient comanagement in the intensive care unit (ICU) and on the routine inpatient unit was provided by a group of hospital-employed and private practice internal medicine hospitalists, with intensivist consultation available on request.

The dissemination and implementation of our PSH occurred in 2 sequential phases. Study data were collected only during the second phase, which represented our full PSH model. During the 24-month period from October 1, 2010, to September 30, 2012, phase 1 of our PSH model was fully operational. The principal element of phase 1 was a preoperative assessment, consultation, and treatment (PACT) clinic, with its widely expanded scope of services and new staffing model (Figure 1). This expansion included an onsite attending anesthesiologist working in collaboration with a team of nurse practitioners. A series of laboratory testing, electrocardiogram, cardiac risk-stratification and testing, and preoperative medication protocols were implemented. A pharmacist-based preoperative medication reconciliation program and a regional analgesia patient education/consent process were also implemented in the PACT clinic. During phase 1 of our PSH model, postoperative patient comanagement in the ICU and on the routine inpatient units was still provided primarily by the group of internal medicine hospitalists.

During the subsequent 24-month period from January 1, 2013, to December 31, 2014, phase 2 of our PSH model was fully operational. The additional principal element of phase 2 was an anesthesia-intensivist and a cadre of nurse practitioners (ie, an "anesthesia-intensivist care team") caring for surgical patients postoperatively while they were both in the ICU and on the routine inpatient unit (Figure 1). This anesthesia-intensivist care team cared for these patients on a continuous basis (24-hour a day coverage with daily rounds) while they were in the hospital. This new postoperative care service was initiated (piloted) on October 1, 2012, but was not fully operational until January 1, 2013. The participation of this anesthesia-intensivist care team (patient comanagement) occurred via an order ("consult") placed in the postanesthesia care unit (PACU) by the orthopedic surgical service. This consult order was placed solely at the discretion of the orthopedic surgical service.

To reduce selection bias, the enrolled and analyzed POST-PSH group consisted of all consecutive patients undergoing THA or TKA who underwent surgery during the 24-month period from January 1, 2013, to December 31, 2014. All of the POST-PSH group patients were evaluated by our PACT clinic. A subset of the POST-PSH group patients was cared for postoperatively by our anesthesia-intensivist care team.

To confirm that the POST-PSH-phase 1 and POST-PSH-phase 2 patients had received the aforementioned 2 primary elements of our PSH model care, we determined (a) using

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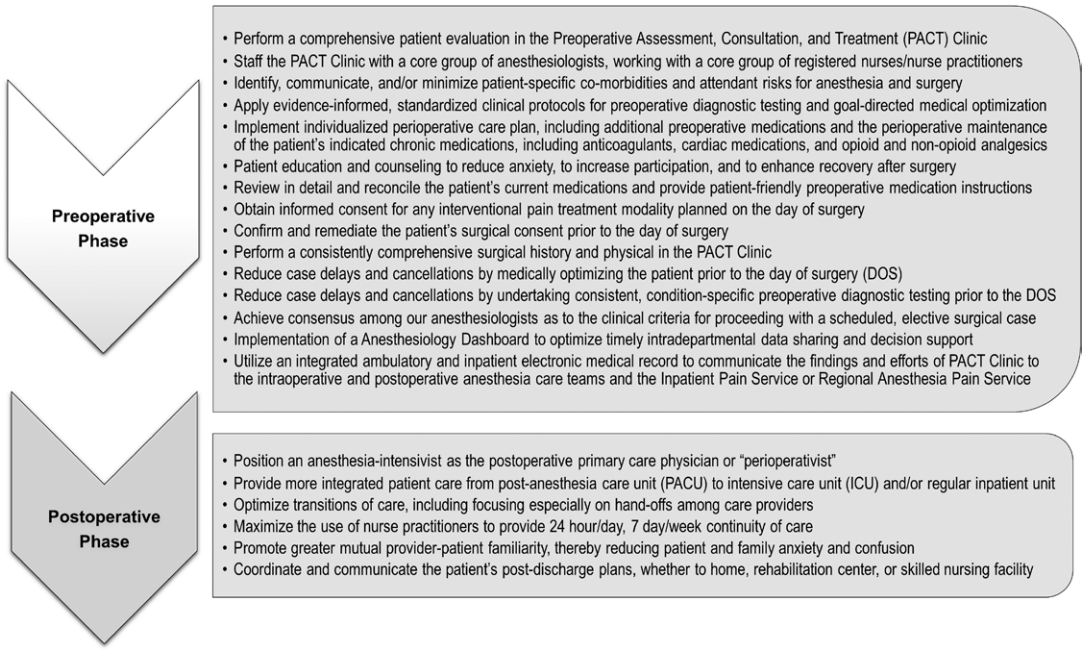

Figure 1. The key additional preoperative and postoperative elements of the Perioperative Surgical Home model at the University of Alabama at Birmingham.

our scheduling database whether a patient had an associated preoperative encounter in our PACT Clinic and (b) using our administrative claims database whether a patient was billed for postoperative care by an anesthesia-intensivist.

There was no standardized anesthesia technique for THR and TKR throughout the entire 6-year study time period. There was an active regional anesthesia pain service throughout the entire study time period; however, no major changes were made in the analgesic regimens or techniques used between the 2 study groups. Likewise, postoperative mobilization and physical therapy were unchanged. Throughout the entire 6-year study time period, there were no major changes in surgical technique (eg, anterior versus posterior approach for a THA and use of tranexamic acid to reduce surgical bleeding).

We did not implement a preoperative anemia management program as a component of our PSH model. As part of an institutional initiative to reduce blood product utilization, however, an intraoperative and postoperative restrictive red blood cell transfusion trigger of <8 g/dL in hospitalized, stable patients[10] was recommended for patients in the entire POST-PSH Group. In stable patients, the recommended practice was also transfusing 1 unit of red blood cells and then clinically reevaluating.

Study Variables

Basic demographic and clinical variables were collected on all study patients. The patient's American Society of Anesthesiologists Physical Status Classification System score (ASA PS score) was assigned immediately before surgery by the assigned attending anesthesiologist. On the basis of conventional clinical risk stratification and to allow for easier clinical interpretation of the data, we elected to collapse the collected patients' ASA PS scores into the dichotomous categories of low score (raw ASA PS scores of 1 or 2) and moderate/high score (raw ASA PS scores of 3 or 4). We were unable to extract from our study subjects' electronic medical records the consistently valid patient-specific (granular) clinical data needed to generate a more robust Charlson Comorbidity Score.[11]

To evaluate the 2 specific aims of this study, a series of clinical, quality, safety, operational, and financial outcome variables (Supplemental Digital Content, Appendix B, http://links.lww.com/AA/B577) were extracted for all PRE-PSH and POST-PSH patients from their initial, acute postoperative hospitalization. Study data were extracted from our institutional electronic scheduling and claims database (GE Centricity Business, GE Healthcare, Wauwatosa, WI); electronic health record repository (PowerInsight, Cerner Corp., Kansas City, MO); and financial administrative database (McKesson Performance Analytics, McKesson Corp., San Francisco, CA). The cost data represented the gross billing charges by the hospital. The cost data did not include the professional fees of the surgeon, anesthesiologist, or hospitalist. All of the extracted cost data were adjusted to December 2014 US dollars using the federally published consumer price index for medical care.[a] Complete data were successfully extracted for all the study variables on 100% of the currently enrolled patients.

Statistical Analysis

Continuous variables were reported as a mean and standard deviation (SD), or if the data were skewed, as a median and interquartile range (IQR). Continuous data were assessed for normality with a Shapiro-Wilk test and by examining Q-Q plots, and if non-normally distributed, they were analyzed as such. Normally distributed data were compared between groups via a *t*-test with nonequal variances. Non-normally

[a]US Department of Labor, Bureau of Labor Statistics. Databases, Tables and Calculators by Subject. Available at: http://data.bls.gov/timeseries/CUUR0000SAM?output_view=pct_12mths. Accessed June 2, 2015.

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distributed data were compared via a Mann-Whitney *U* test. Categorical variables were reported with frequency counts and percentages. Categorical data were compared between groups with a χ^2 test or Fisher exact test with cell sizes less <5. Absolute standardized difference scores have been recommended for comparing baseline covariates in clinical trials as well as with nonrandomized, observational study data to reduce the potential for a practically insignificant difference achieving statistical significance solely based on a large sample size.[12,13] An absolute standardized difference score also was thus calculated for all study group baseline covariates.

We also used a series of binary logistic regression models to assess the association between the individual dichotomous-dependent outcome variables (day of surgery on-time start, day of surgery anesthesia-related delay, ICU admission, 30-day readmission) and the study group assignment, controlling for the potential confounding effect of the significant independent covariates of sex (female/male); type of surgery (THA or TKA); ASA PS score (1/2 or 3/4); and surgeon ("A, B, or C"). Age and race were considered but not included in the final models because they did not demonstrate significance in the intergroup bivariate analyses (Table 1). The logistic regression models used a forced entry method. All variables significant in initial bivariate analysis at $P < .05$ were forced into the models.

Table 1. Demographic and Clinical Characteristics of the Study Participants

Variable	PRE-PSH (A) N = 1225	POST-PSH (B) N = 1363	A vs B *P*	Absolute Standardized Difference score
Age, mean ± SD	60.8 ± 13.7	61.7 ± 12.9	.061	0.07
Sex, n (%)			.037	0.08
Female	747 (61)	776 (57)		
Male	478 (39)	587 (43)		
Race, n (%)			.144	0.09
Caucasian	814 (66)	949 (70)		
African American	399 (33)	394 (29)		
Other	12 (<1)	20 (1)		
Surgery type, n (%)			.048	0.08
Total hip arthroplasty	577 (47)	695 (51)		
Total knee arthroplasty	648 (53)	668 (49)		
Surgery type, n (%)				
Primary arthroplasty	928 (76)	984 (72)	.040	0.09
Revision arthroplasty	297 (24)	379 (28)		
ASA classification, n (%)			<.001	0.27
I	7 (<1)	8 (<1)		
II	404 (33)	270 (20)		
III	803 (66)	1071 (78)		
IV	11 (<1)	14 (1)		
V	0 (0)	0 (0)		
Surgeon, n (%)			<.001	0.33
A	459 (38)	731 (54)		
B	398 (33)	379 (28)		
C	330 (27)	168 (12)		
Other	38 (3)	84 (6)		

Abbreviations: ASA, American Society of Anesthesiologists; POST, post; PRE, pre; PSH, Perioperative Surgical Home; SD, standard deviation.

We used a multivariable linear regression model to assess the differences between the individual continuous dependent outcome variables (hospital length of stay and ICU days) and the study group assignment, controlling for the potential confounding effect of the significant independent covariates of sex (female/male); type of surgery (THA or TKA); ASA PS score (1/2 or 3/4); and surgeon ("A, B, or C"). We also calculated multivariable associations for financial data for the patients undergoing THA or TKA, controlling for ASA PS score and surgeon. These linear regression models used a forced entry method. All variables significant in initial bivariate analysis at $P < .05$ were forced into the models.

Given the relatively short, immediate perioperative data collection period (date of surgery to 30 days postoperatively), loss to follow-up was not considered. Three ICU patient subgroups were analyzed (Table 3), but no variable interactions were analyzed. No sensitivity analyses were performed. No a priori sample size determination and power analysis were performed. The study sample sizes instead were based on the programmatic 24-month preintervention and postintervention time periods. Our resulting sample sizes had 90% power to detect a 5.4% difference in day of surgery on-time start rate and a $280 difference (with an assumed SD of $2137) in direct, nonsurgical cost, both with an alpha of 0.05. For all statistical analyses, a *P*-value of <.05 was considered significant. Statistical analyses were performed using SAS, Version 9.3 (SAS Institute Inc, Cary, NC).

RESULTS

Patients were stratified by the time period during which they received their perioperative care, as described previously. A total of 1225 THA/TKA patients were identified and included in the PRE-PSH group. A total of 1363 THA/TKA patients were identified and included in POST-PSH group. Of these 1363 POST-PSH patients, 420 patients were evaluated preoperatively in our PACT clinic and received postoperative care from our anesthesia-intensivist care team (Figure 2).

There were no significant differences in age ($P = .061$) or racial composition ($P = .14$) between the study groups. There were significant differences between the study groups in sex proportion ($P = .037$), proportion of THA patients versus TKA patients ($P = .048$), and proportion primary arthroplasty patients versus revision arthroplasty patients ($P = .040$); however, all with an absolute standardized difference score of <.10. There was a significant difference between the study groups in ASA PS scores ($P < .001$) with an absolute standardized difference score of 0.30. There was a significant difference in the distribution of surgical cases among the participating surgeons ($P < .001$) (Table 1).

Clinical, Quality, and Patient Safety Outcomes

Bivariate (Unadjusted) Analyses. The observed mortality rate was 0% in the PRE-PSH group and POST-PSH group. There were only 2 observed significant group differences in the clinical, quality, and patient safety outcome variables (as listed in Appendix B, http://links.lww.com/AA/B577). Specifically, 12% (95% confidence interval [CI], 9.6%–14.4%) more patients in the POST-PSH group versus

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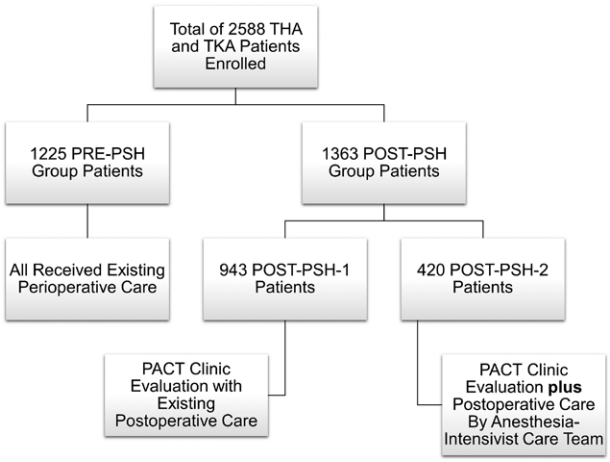

Figure 2. Enrollment process and flow diagram for this retrospective observational study.

PRE-PSH group received blood clot preventive therapy 24 hours before and 24 hours after surgery ($P < .001$). A total of 325 (26.5%) patients in the PRE-PSH group versus 219 (16.1%) patients in the entire POST-PSH group received a red blood cell transfusion during their initial surgical hospitalization ($P < .001$). This observed 10.4% (95% CI, 7.3%–13.5%) difference blood transfusion rate equated to a crude odds ratio of 0.53 (95% CI, 0.43–0.64; $P < .001$). The patients transfused in PRE-PSH group received marginally significantly more units of red blood cells (median of 2, IQR 1–3) than the patients transfused in the POST-PSH group (median of 2, IQR 1–2) ($P = .047$).

Operational Outcomes

Bivariate (Unadjusted) Analyses. When compared with the PRE-PSH Group, the POST-PSH group was associated with a 7.2% (95% CI, 4.0%–10.4%) increase in day of surgery on-time starts ($P < .001$), a 5.8% (95% CI, 3.1%–8.5%) decrease in day of surgery anesthesia-related delays ($P < .001$), and a 2.2% (95% CI, 0.5%–3.9%) decrease in ICU admission rate ($P = .011$) (Table 2).

The observed same-day cancellation rate was 19.4% (295 of 1420 total scheduled THA and TKA cases) in the PRE-PSH time period versus 14.4% in the POST-PSH time period (229 of 1592 total scheduled THA and TKA cases) ($P < .001$). This observed 5.0% (95% CI, 2.4%–7.6%) difference in the same-day cancellation rate equated to a crude odds ratio of 0.70 (95% CI, 0.57, 084; $P < .001$). No adjustment for ASA PS scores was performed because these scores were not assigned routinely by the attending anesthesiologist on the day or surgery for patients cancelled on the day of surgery.

Further analysis of the ICU admissions revealed a 0.6 (95% CI, 0.5–0.7) decrease in the number of ICU days in the POST-PSH group compared with the PRE-PSH group ($P = .028$) (Table 2). A significantly greater proportion (33.3%, 95% CI, 16.9%–49.7%) of patients in the POST-PSH group were admitted directly from the PACU to the ICU ($P < .001$), whereas a significantly greater proportion (30.8%, 95% CI, 13.9%–47.7%) of patients in the PRE-PSH group were admitted first from the PACU to a routine inpatient unit, and then to the ICU ($P < .001$) (Table 2).

There was no significant difference (0.1 day; 95% CI, −0.03 to 0.23) in the total hospital LOS between the 2 study groups ($P = .14$). There was also no significant difference (1.2%; 95% CI, −0.6 to 3.0) in the all-cause readmission rate between the study groups ($P = .18$).

Multivariate (Adjusted) Analyses. Two of these bivariate operational differences were further analyzed with multivariable regression models. After considering the potential confounding effect of the significant independent covariates of sex (female/male), type of surgery (THA or TKA, and primary or revision), ASA PS score (1/2 or 3/4), and surgeon (A, B, or C), we found an associated increase (β-coefficient) of 0.04 (95% CI, −0.09 to 0.18) day in the hospital length of stay ($P = .54$). After considering the potential confounding effect of the significant independent covariates of sex (female/male), type of surgery (THA or TKA), and ASA PS score (1/2 or 3/4), there was an associated decrease (β-coefficient) of 0.6 (95% CI, −1.1 to −0.04) day in ICU days ($P = .036$).

The remaining bivariate operational differences were further analyzed with logistic regression models that controlled for the significant independent covariates of sex, type of surgery, ASA PS score, and surgeon. The resulting adjusted odds ratios are reported in Table 3.

Table 2. Unadjusted Associations Between Pre-PSH and Post-PSH Patients and Operational Variables

PRE-PSH (A)	POST-PSH (B)	A vs B
	N = 1225	N = 1363	*P*
Study variable			
Day of surgery on-time starts, n (%; 95% CI)	908 (74.1; 71.6–76.6)	1108 (81.3; 79.2–83.2)	<.001
Day of surgery anesthesia-related delays, n (%; 95% CI)	206 (16.8; 14.7–18.9)	150 (11.0; 9.3–12.7)	<.001
Observed hospital length of stay, mean days ± SD	3.4 ± 1.6	3.5 ± 1.8	.14
Overall ICU admission rate, n (%; 95% CI)	73 (6.0; 4.7–7.3)	52 (3.8; 2.8–4.8)	.011
ICU admission subgroups			
PACU to ICU admission, n (%; 95% CI)	15 (20.5; 18.2–22.8)	28 (53.8; 51.2–56.4)	<.001
Routine inpatient unit to ICU admission, n (%; 95% CI)	52 (71.2; 68.7–73.7)	21 (40.4; 37.8–43.0)	<.001
ICU readmission (bounce-back), n (%; 95% CI)	6 (8.2; 6.7–9.7)	3 (5.8; 4.6–7.0)	.73
ICU days, mean days ± SD	2.4 ± 1.6	1.8 ± 1.3	.028
30-day readmission, n (%; 95% CI)			
All-cause readmission	62 (5.1; 3.9–6.3)	86 (6.3; 5.0–7.6)	.18
Surgery procedure-related cause readmission	51 (4.2; 3.1–5.3)	57 (4.1; 3.0–5.2)	.99

Abbreviations: CI, confidence interval; ICU, intensive care unit; PACU, postanesthesia care unit; POST, postintervention; PRE, preintervention; PSH, Perioperative Surgical Home; SD, standard deviation.

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The outcome variable of day of surgery on-time start rate was also plotted over time for the Pre-PSH group and the Post-PSH group, with temporal trend lines (Figure 3). These trend lines demonstrated an apparent qualitative difference between the 2 groups.

Table 3. Logistic Regression Models of the Operational Data for the Study Participants

	POST-PSH Group (N = 1363) vs PRE-PSH Group (N = 1225)	
Study variables	**aOR (95% CI)**	***P***
Day of surgery on-time start	2.54 (1.70–3.80)	<.001
Day of surgery anesthesia-related delay	0.66 (0.52–0.84)	<.001
Overall ICU admission	0.45 (0.31–0.66)	<.001
PACU to ICU admission	4.57 (2.01–10.36)	<.001
Routine inpatient unit to ICU admission	0.27 (0.12– 0.58)	<.001
ICU readmission (bounce-back)	0.75 (0.17–3.33)	.71
30-day readmission		
All cause	1.08 (0.76–1.54)	.59
Cause-related to surgery procedure	0.81 (0.54–1.21)	.30

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval; ICU, intensive care unit; PACU, postanesthesia care unit; POST, postintervention; PRE, preintervention; PSH, perioperative surgical home.

Financial Outcomes

Multivariate (Adjusted) Analyses. Because the 2 phases of our PSH model at UAB involved mainly the preoperative and postoperative elements of care, we focused primarily on the direct nonsurgery cost, which excluded the costs associated with intraoperative and PACU care. Compared with the PRE-PSH group, the entire POST-PSH group was associated with a $432 (95% CI, 270–594) decrease in direct nonsurgery costs for the THA ($P < .001$) and a $601 (95% CI, 430–772) decrease in direct nonsurgery costs for the patients undergoing TKA ($P < .001$) (Table 4). These decreased direct nonsurgery costs for patients undergoing THA or TKA included categories that were likely impacted by the PACT clinic and the "anesthesia-intensivist care team" (Table 5).

Nevertheless, compared with the PRE-PSH group, the POST-PSH group was associated with a significantly increased direct surgery costs for the patients undergoing THA ($P < .001$) and TKA ($P < .001$) (Table 4). This difference was largely due to the increased cost of operating room time, surgical equipment, and surgical supplies, including the hip and knee joint implants (Supplemental Digital Content, Appendix C, http://links.lww.com/AA/B578).

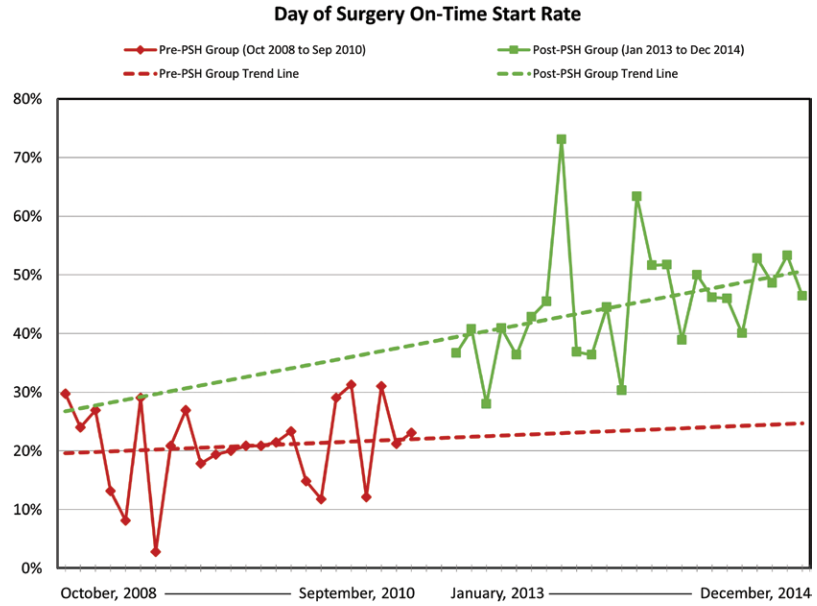

Figure 3. Outcome variable of day of surgery on-time start rate plotted over time for the initial Pre-Perioperative Surgical Home Group and the subsequent Post-Perioperative Surgical Home Group, with temporal trend lines.

Table 4. Financial Data for the Study Participants (All in December 2014 US Dollars)

	PRE-PSH (A)	POST-PSH (B)	A vs B
Study variable	**N = 1225**	**N = 1363**	***P***
Total direct medical cost, mean ± SD	$12,676 ± $5707	$15,273 ± $7356	<.001
All THA patients, mean ± SD			
Direct surgery cost	$7,520 ± $3386	$9,779 ± $4710	<.001
Direct cost excluding surgery cost	$4,749 ± $2235	$4,317 ± $1933	<.001
All TKA patients, mean ± SD			
Direct surgery cost	$7,970 ± $3588	$11,826 ± $5696	<.001
Direct cost excluding surgery cost	$5,226 ± $2137	$4,625 ± $2291	<.001

Abbreviations: POST, postintervention; PRE, preintervention; PSH, perioperative surgical home; SD, standard deviation; THA, total hip arthroplasty; TKA, total knee arthroplasty.

DISCUSSION

Our present PSH clinical proof-of-concept study indicates a positive association between the sequential introduction of the preoperative and postoperative elements of the initial UAB PSH model and a subset of (1) clinical, quality, and patient safety outcomes and (2) operational and financial outcomes in patients undergoing THA or TKA. We posit that our initial PSH model and findings at UAB, which focused primarily on the preoperative and postoperative phases of care in a similar population of patients undergoing THA or

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Table 5. Cost Category Changes Between the Pre-PSH and Post-PSH Study Groups

	Total Knee Arthroplasty Patients	Total Hip Arthroplasty Patients
	Pre-PSH Group to Post-PSH Group % Change	Pre-PSH Group to Post-PSH Group % Change
Direct cost category		
Anesthesiology	−24.1	+1.4
Blood bank	−2.4	+2.1
Central supply	+90.7	+95.7
Lab	−64.3	−36.8
Nursing	+21.2	+13.4
Pharmacy	−12.8	−4.2
Radiology	−71.9	−0.8
Respiratory therapy	−93.2	−110.6
Physical therapy	−35.4	−35.0

Abbreviations: POST, postintervention; PRE, preintervention; PSH, perioperative surgical home.

TKA, complement the efforts and previously reported findings from the University of California Irvine (UCI).

The previous PSH model and data reported by the team at UCI focused primarily on the intraoperative phase of care. The UCI team applied lean methodology to reduce unnecessary variability in the anesthetic and surgical care of THA and TKA patients.[14] In a preliminary feasibility project, they developed, implemented, and assessed a series of clinical care pathways that defined and standardized management for patients undergoing elective primary THA (n = 51) and TKA (n = 95). Their rigorous standardization of care was associated with a number of positive outcomes, including an incidence of major complications of 0%; in-hospital mortality of 0%; perioperative blood transfusion of 6.2%; and 30-day readmission of 0.7%. All Surgical Care Improvements Project measures were met at 100%. The median (IQR) LOS for THA and TKA was 3 (2–3) and 3 (2–3) days, respectively. Approximately, 50% of the enrolled patients were discharged to a location other than their customary residence (70 to skilled nursing facility and 1 to rehabilitation). A parallel financial review of this initial UCI Total Joint Replacement PSH revealed a total per diem cost (mean ± SD) of $9952 ± $1294 for THA and $10,042 ± $1305 for TKA versus a literature-reported benchmark per diem cost of $16,267 for THA and $17,588 for TKA.[15]

Our current findings also confirm those of 2 previous studies demonstrating the advantages of an anesthesiology-based preoperative clinic visit. We sought to build on these earlier findings by incorporating a robust PACT clinic into our UAB PSH model.

At the University of Chicago, in their general operating rooms, 5.3% of patients evaluated in its anesthesia preoperative medicine clinic were cancelled, compared with 13.0% of patients without such a clinic visit ($P < .001$). Cancellations also were more likely to occur among patients with greater ASA PS scores ($P < .001$).[16]

At the Weiner Center for Preoperative Evaluation at Brigham and Women's Hospital, attention was focused on medical problems requiring further information or management. New problems had a far greater probability of delay (10.7% vs 0.6%) or cancellation (6.8% vs 1.8%) than old (existing) problems. Most of the new medical problems required that a new test or consultation be done, whereas most of the old problems required retrieval of information existing from outside clinics or medical centers. The majority of issues identified were cardiac in origin.[17] The experience in our UAB PACT Clinic was very similar.

Patients in our POST-PSH group had significantly greater ASA PS scores and thus greater comorbidity. This likely reflected that with the implementation of the second element of our PSH model—namely, an anesthesia-intensivist staffing of the UAB Highlands Hospital ICU and routine inpatient units—fewer THA and TKA patients with major comorbidity were alternatively scheduled for their planned surgery at the main UAB Hospital, which presumably resulted in less disruption in patient care and surgeons' operating room block time utilization.

The model of physician staffing in the ICU at UAB Highlands changed from a "low intensity" model in the PRE-PSH period, consisting of hospitalists staffing the ICU with intensivist consultation available, to a "high intensity" model in the POST-PSH period, when all patients admitted to the ICU were under the care of an intensivist. The reduction in ICU LOS during the POST-PSH period is consistent with previous studies demonstrating reduced ICU LOS under "high-intensity" ICU physician staffing models.[18] This reduction in overall ICU admissions during the POST-PSH period suggests a positive influence of our PSH model on the overall need for ICU-level care. Our observed lower rate of ICU admission and ICU LOS during the POST-PSH period, however, may have been related to better triage or simply a redesign of the system.

Interestingly, although we observed an overall decrease in ICU admissions, there was a significant increase in the proportion of patients in the ICU who were admitted to the ICU immediately postoperatively—as opposed to initial admission to a routine inpatient unit followed by transfer to the ICU—in our POST-PSH group (53.8%) versus in our PRE-PSH group (20.5%). This finding likely reflected a greater tendency to preemptively admit patients to the ICU after the creation of a specialty ICU service, in a setting such as ours, where the ICU service was integrated fully into the postoperative care continuum. It also may have resulted from the aforementioned greater patient comorbidity in the POST-PSH group compared with the PRE-PSH group. Earlier admission to the ICU also may have contributed to the reduction in ICU LOS, by allowing earlier recognition of problems, with the opportunity for more rapid correction. The presence of an intensivist-led ICU team also was associated with a reduction of readmissions to the ICU during the same hospitalization.

Our present efforts were intended to serve as a clinical proof-of-concept: (a) to confirm the viability of our working PSH prototype, with the necessary functionality and infrastructure and thus (b) to answer a "Go-No Go" decision about further program development and resource investment.[5] Furthermore, our clinical proof-of-concept process emphasized the identification of previously unforeseen challenges and pitfalls unique to our particular environment to save time and resources and to improve efficiency when a more robust, future model is implemented.[4,5]

In the interim since December 2014 (the closing date for our current post-PSH data collection), we have begun developing and implementing a series of Perioperative Risk Optimization and Management Protocols (PROMPTs),[19] each of which targets a specific clinical condition. This effort reflects the continually evolving nature of our PSH model at UAB.

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Limitations

Given the pragmatic yet nonrandomized study design that we applied, there was a potential for unrecognized confounding. Although not obvious during our 6-year data collection period, such potential confounders included unrecognized changes in operating room management, performance-based financial incentives/penalties, surgical practice, pain management, and rehabilitation regimens. The risk of the potential confounding effects of these unrecognized practice changes (eg, on on-time starts and reduced anesthesia-related delays) was significantly increased because of the sustained time period between the 2 study groups.

As noted herein, we were unable to extract from our study subjects' electronic medical records, the consistently valid patient-specific (granular) clinical data needed to generate a more robust Charlson Co-Morbidity Score,[11] and to undertake more rigorous propensity score matching.[20] Our use instead of ASA PS scores may not have controlled adequately for the confounding effect of patient comorbidity.

Given the sequential nature of our 2-phase PSH model implementation and our single-blinded (patients only) study design, a Hawthorne effect may have occurred, whereby the involved health care providers may have changed their behavior in response to their performance being monitored. This potential bias was mitigated by the sustained 24-month postintervention period, as well as the lack of any interim outcomes and provider-level performance data analyses and internal reporting.

Because a significant benefit could have been realized as the result of process redesign that improved work flow and shortened throughput, and thus decreased number of involved staff, applying a time-driven activity-based costing[21] would have demonstrated more accurate, perhaps even greater improvements.

Lastly, as reported by Garson et al[14] and Cyriac et al[22] at UCI, as well as Auyong et al[23] at Virginia Mason Medical Center in Seattle, a more robust perioperative total joint replacement care pathway, which included standardized multimodal analgesia and earlier mobilization and physical therapy, likely would have resulted in even more favorable outcomes.

Future Research

Elements of the PSH and similar surgical care coordination models have been studied in the United States and other developed countries.[24] However, despite the ASA and other early adopters advocating the PSH to be the optimal global model of care for surgical patients,[1–3,25–29] there have been only a small number of published studies providing validation of this new model of care.[14,15,30] Therefore, there is a need for additional studies that demonstrate that incorporating the PSH promotes patient-centeredness and optimizes the value of surgical patient care.

More externally valid and hence important information could be obtained by simultaneously developing elements of the PSH at several institutions with different population health—for example, through the ASA-sponsored PSH Learning Collaborative.[31]

For example, an important specific focus of future PSH research should be the posthospital discharge phase of care. Indeed, because of pressure on the hospitals to shorten the length of stay of surgical patients, patients with multiple comorbidities and/or who underwent complex surgery often are transferred to skilled nursing facilities. The cost of these skilled facilities continues to increase every year, with many surgical patients never returning to live at home.[32–34] The cost-effectiveness and cost-utility of care provided by these postsurgical facilities, including hospital readmission and health-related quality of life during the first 30–90 days after hospital discharge, should be evaluated in future PSH studies.

Lastly, this future research will likely involve a strong reiterative, continuous quality improvement component based on process learning and outcome evaluation.[35] This continuous quality improvement can be readily performed by applying Plan-Do-Study-Act cycles or closely related Plan-Do-Check-Act cycles.[35,36]

CONCLUSIONS

On the basis of our preliminary findings, it appears that our initial PSH model at UAB with its expanded role of the anesthesiologist as the "perioperativist"[3] can be associated with improvements in the operational outcomes of increased on-time surgery starts and reduced anesthesia-related delays and decreased selected costs in patients undergoing THA or TKA. Although the day-of-surgery case cancellation rate also significantly decreased after implementing our PSH model, it remained elevated, representing an opportunity for additional process improvement.

These exploratory findings have supported our departmental and institutional "Go" decision to continue to expand the scope of our PSH model. We have begun a series of more focused confirmatory studies, examining the various components of our expanding PSH model. ■

DISCLOSURES

Name: Thomas R. Vetter, MD, MPH.
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Contribution: This author participated in the study design, study conduct, data collection, data analysis and interpretation, and manuscript preparation.
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