Hypotension and Outcomes

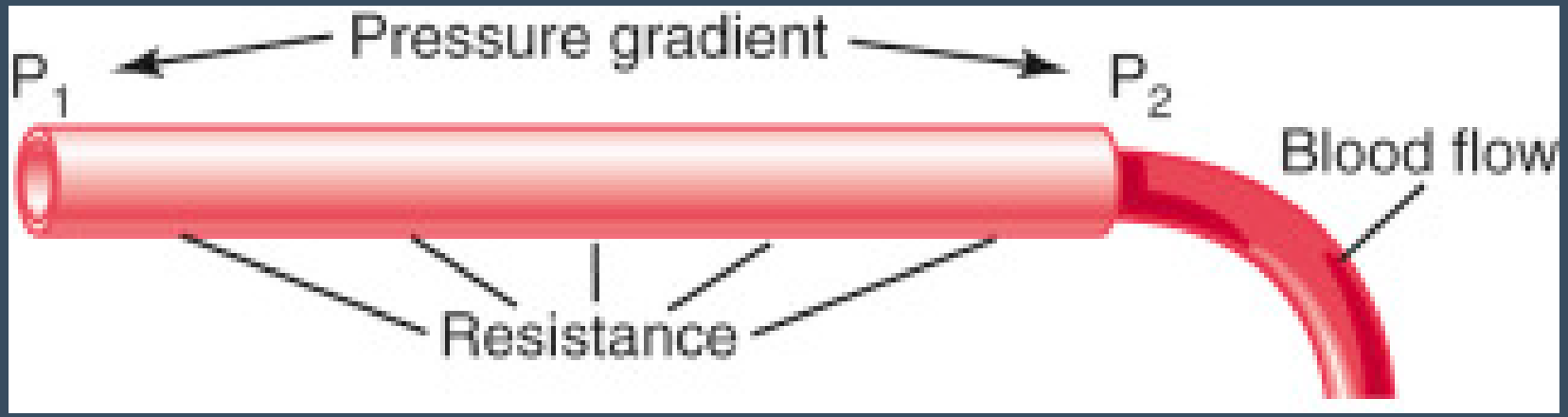
Kamal Maheshwari MD MPH
Associate Professor of Anesthesiology
@kamalmaheshwar7

Cleveland Clinic

- Why should we avoid hypotension?
  - *To maintain organ perfusion*
  - *To optimize the quality of care*
  - *To avoid complications*
  - *To optimize cost*
- How hypotension should be avoided?
  - *Prediction*
  - *Appropriate diagnosis*
  - *Appropriate treatment*

Organ Perfusion

Perfusion → Flow per unit tissue weight.



$$F = \frac{\pi \Delta P r^4}{8 \eta l}$$

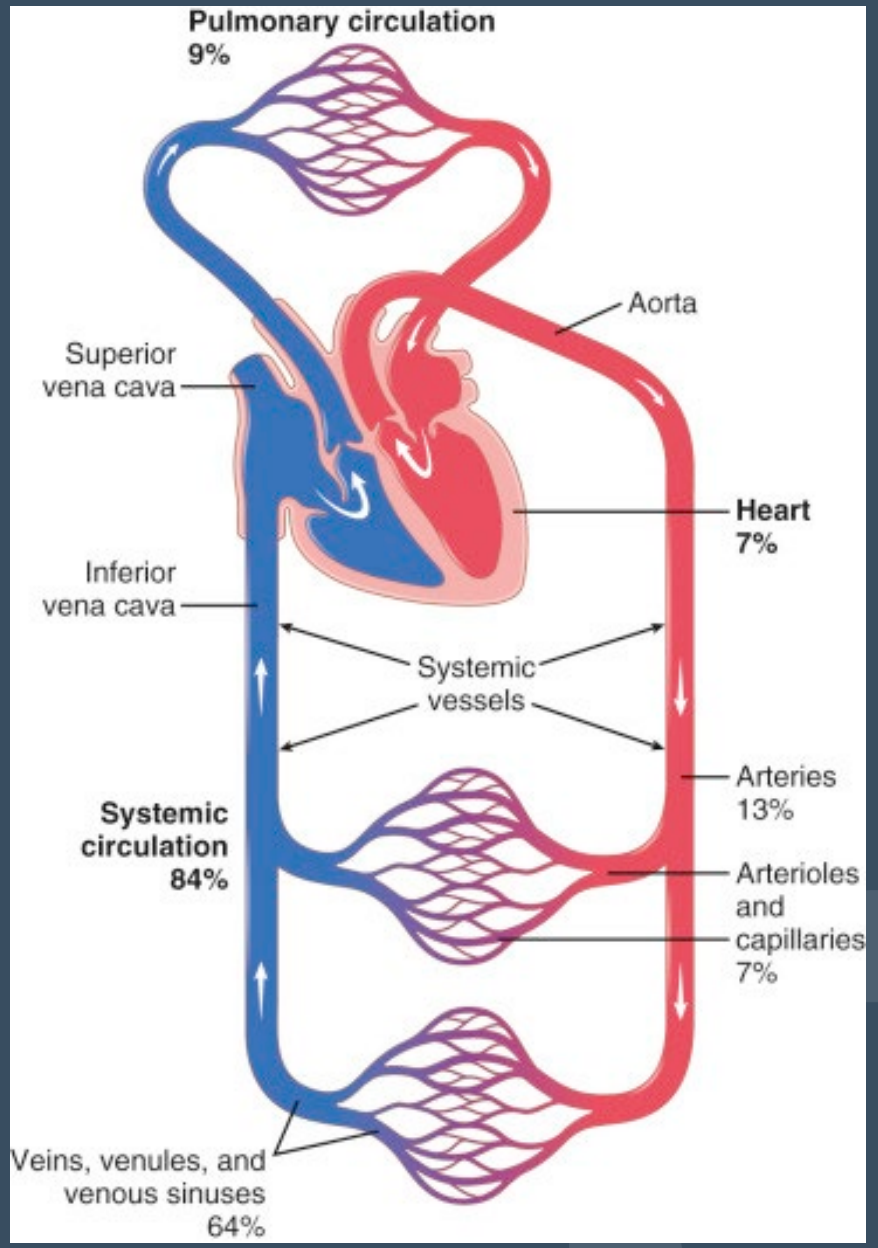
Guyton and Hall Textbook of Medical Physiology, Chapter 14, 169-178

Low blood pressure

Poor organ perfusion

Complications

Mortality

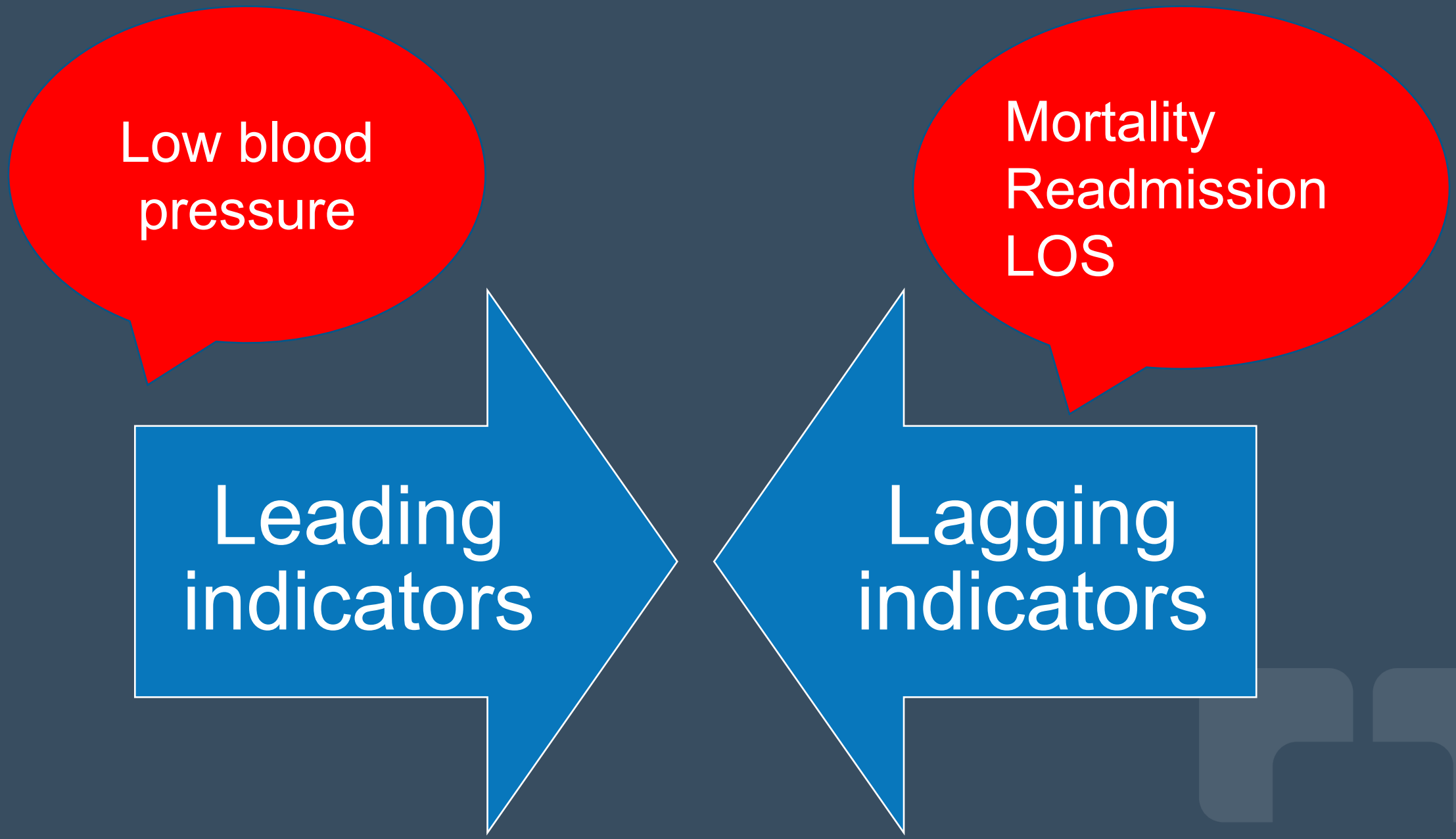


Guyton and Hall Textbook of Medical Physiology, Chapter 14, 169-178

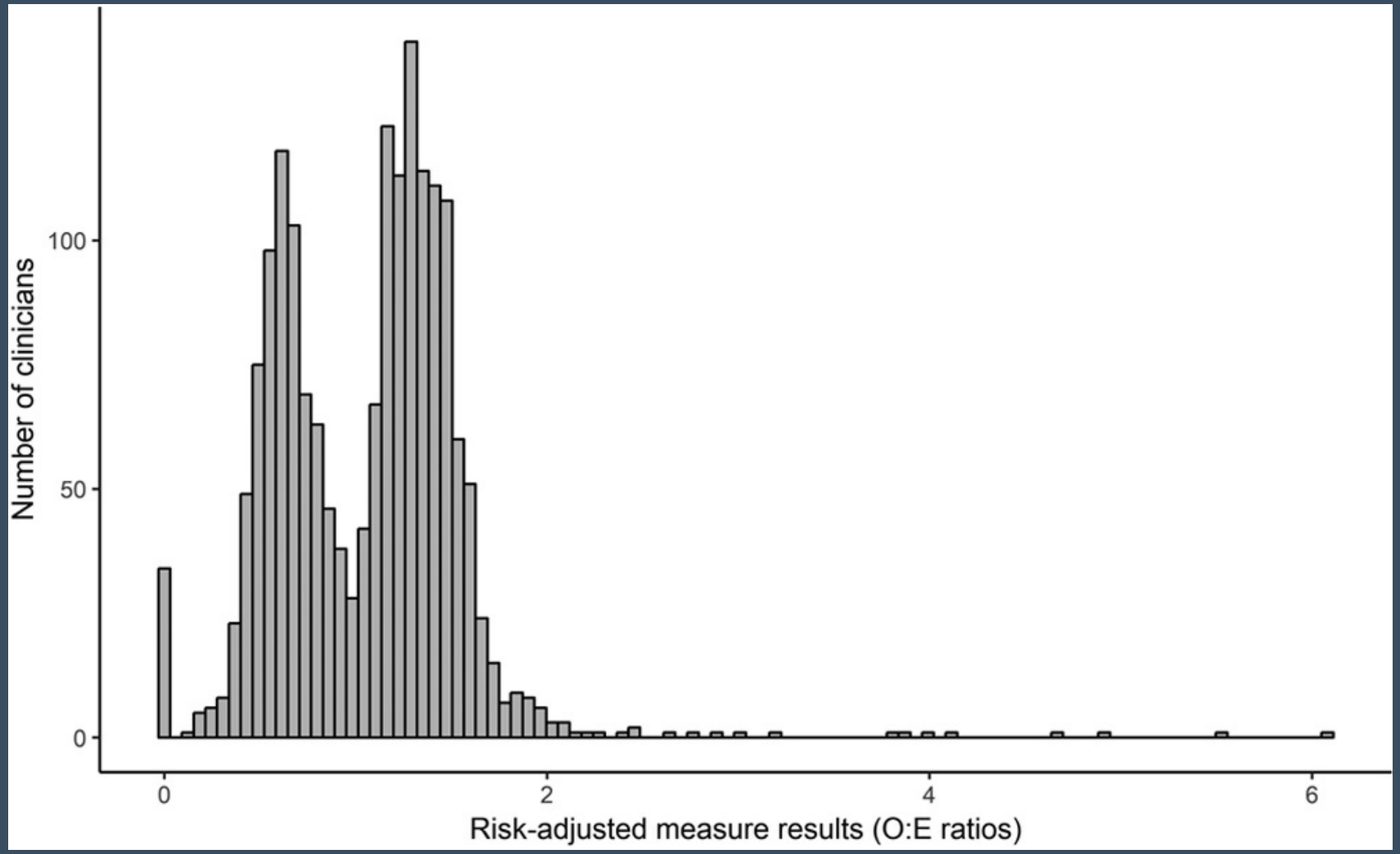
Quality

- "the degree to which health care services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge"
- "by empowering perioperative teams to explore variation in practice and identify opportunities for change"

Institute of Medicine
https://mpog.org/quality/

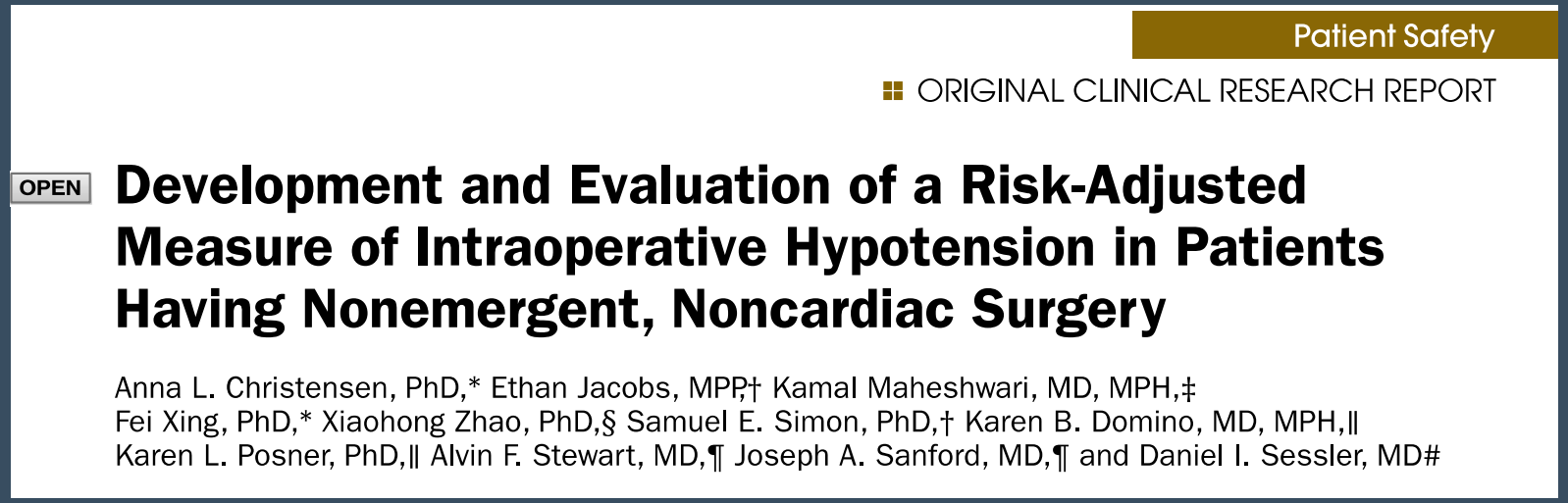

Low blood pressure
Mortality
Readmission
LOS
Leading indicators
Lagging indicators

Hypotension as quality metric



Anesthesia & Analgesia133(2):445-454, August 2021

Hypotension as quality metric



Patient Safety

ORIGINAL CLINICAL RESEARCH REPORT

OPEN

Development and Evaluation of a Risk-Adjusted Measure of Intraoperative Hypotension in Patients Having Nonemergent, Noncardiac Surgery

Anna L. Christensen, PhD,* Ethan Jacobs, MPP,† Kamal Maheshwari, MD, MPH,‡
Fei Xing, PhD,* Xiaohong Zhao, PhD,§ Samuel E. Simon, PhD,† Karen B. Domino, MD, MPH,‖
Karen L. Posner, PhD,‖ Alvin F. Stewart, MD,¶ Joseph A. Sanford, MD,¶ and Daniel I. Sessler, MD#

- Metric: Number of cases in one year who qualify for hypotension which is defined as MAP <65 mm Hg for 15 minutes per case

Anesthesia Quality Institute®
American Society of Anesthesiologists®

ePreop
NOW PART OF
provation

Improve Patient Outcomes with the New Intraoperative Hypotension Quality Measure

Approved by the Centers for Medicare & Medicaid Services (CMS) as a Qualified Clinical Data Registry (QCDR) measure within the Merit-Based Incentive Payment System (MIPS) reporting program, the Intraoperative Hypotension (IOH) quality measure supports an increasing desire for objective quality measurement and reporting.

This IOH Measure encourages qualified anesthesia providers to maintain an intraoperative mean arterial pressure (MAP) above 65 mmHg in order to reduce the risk of adverse outcomes such as acute kidney injury and myocardial injury.

ePreop is co-stewarding the IOH Measure with the Cleveland Clinic to promote awareness around non-emergent, noncardiac cases in which a patient's MAP falls below 65 mmHg for a cumulative total of 15 minutes or more.

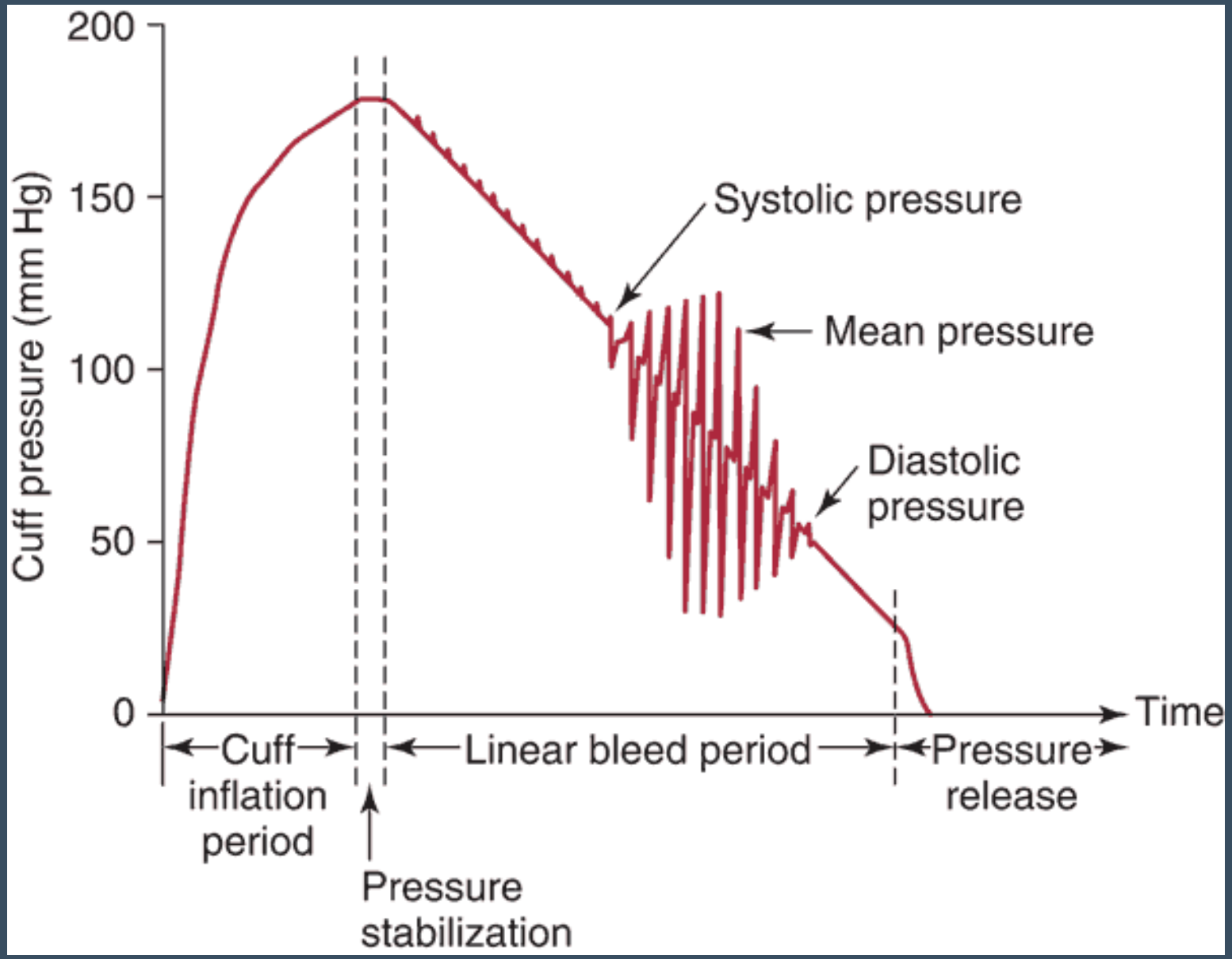
Complications

- 25% (around $1 trillion) of US healthcare spending is waste
  - Avoidable complications
  - Unnecessary readmissions
- Postoperative complications are third leading cause of death [global]

Shrank, JAMA,2019
Nepogodiev, Lancet, 2019

Hypotension and complications

- Operating room
- Ward
- Critical care units



Ehrenwerth J, Eisenkraft JB, Berry JM, eds. Anesthesia Equipment: Principles and Applications. 2nd ed. Philadelphia, PA: Elsevier Saunders; 2013:Figure 12-1

Babbs *BioMedical Engineering OnLine* 2012, **11**:56
http://www.biomedical-engineering-online.com/content/11/1/56

BioMedical Engineering OnLine

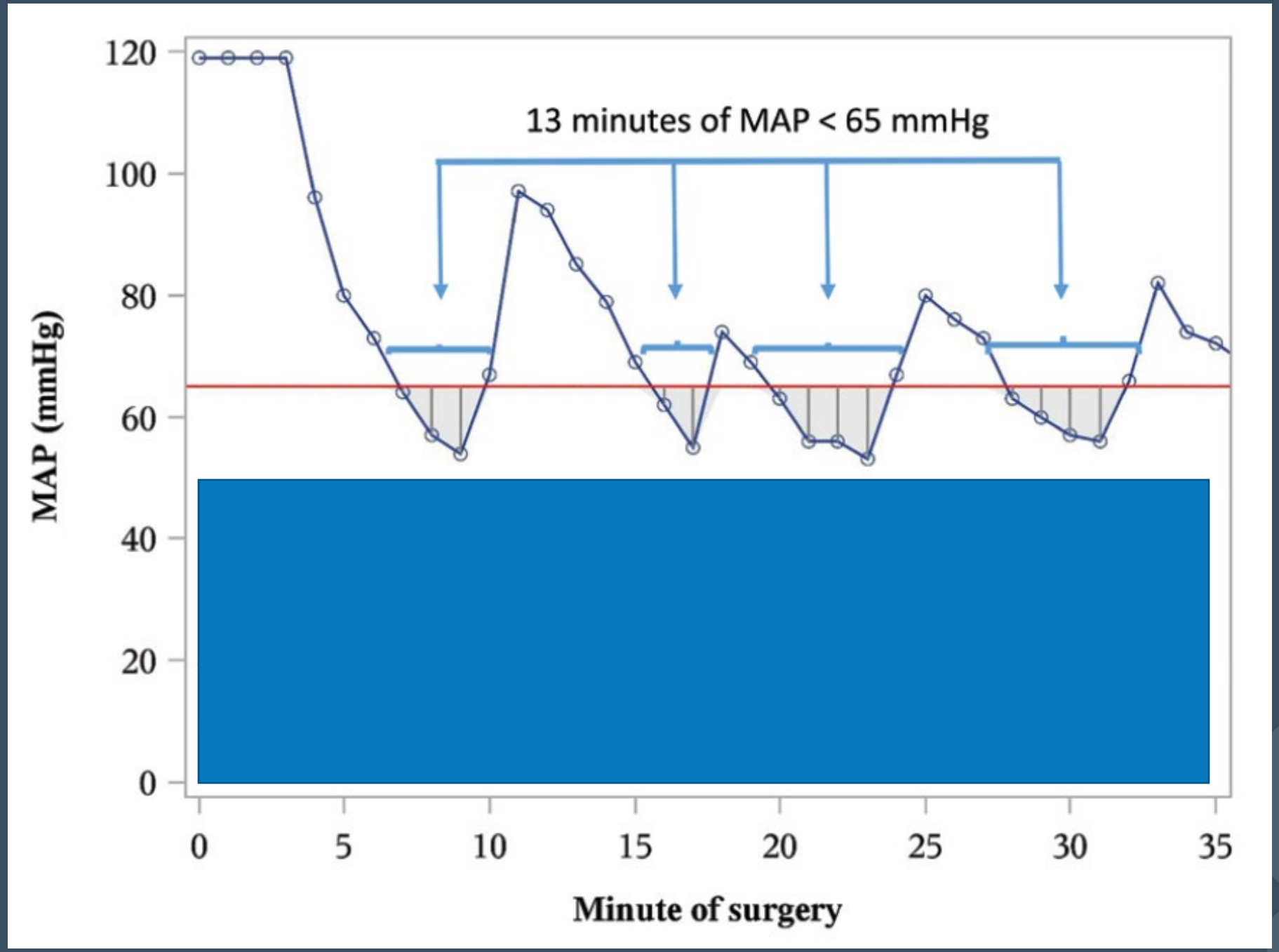
RESEARCH Open Access

Oscillometric measurement of systolic and diastolic blood pressures validated in a physiologic mathematical model

Charles F Babbs

Abstract

Background: The oscillometric method of measuring blood pressure with an automated cuff yields valid estimates of mean pressure but questionable estimates of systolic and diastolic pressures. Existing algorithms are sensitive to differences in pulse pressure and artery stiffness. Some are closely guarded trade secrets. Accurate extraction of systolic and diastolic pressures from the envelope of cuff pressure oscillations remains an open problem in biomedical engineering.



Maheshwari, A&A, 2018

THE LANCET
Volume 371, Issue 9627, 31 May–6 June 2008, Pages 1839–1847

Effects of extended-release metoprolol succinate in patients undergoing non-cardiac surgery (POISE trial): a randomised controlled trial

Lancet 2008; 371: 1839–47
Published Online May 13, 2008
DOI:10.1016/S0140-6736(08)60601-7

	Adjusted odds ratio (95% CI)	Frequency of risk factor n (%)	PAR* (95% CI)
Death			
Preoperative independent predictors			
No use of statin in 24 h before surgery	1·73 (1·22–2·46)	5674 (67·9%)	33·7% (18·3–53·6)
Age ≥70 years	1·65 (1·20–2·26)	4387 (52·5%)	29·3% (16·2–47·0)
Emergent/urgent surgery	3·71 (2·68–5·14)	878 (10·5%)	24·4% (18·0–32·2)
Serum creatinine >175 μmol/L	2·67 (1·75–4·08)	401 (4·8%)	9·5% (5·4–16·0)
History of congestive heart failure	1·76 (1·14–2·72)	535 (6·4%)	6·0% (2·5–13·6)
Use of low-molecular-weight heparin in 24 h before surgery	1·74 (1·14–2·68)	556 (6·7%)	5·9% (2·4–13·8)
Intraoperative and postoperative predictors			
Clinically significant hypotension	4·97 (3·62–6·81)	1029 (12·3%)	37·3% (29·5–45·8)
Myocardial infarction without ischaemic symptoms	3·45 (2·20–5·41)	271 (3·3%)	10·6% (6·4–17·0)
Significant bleeding	1·67 (1·14–2·44)	553 (6·6%)	9·4% (4·3–19·5)
Stroke	18·97 (9·93–36·25)	60 (0·7%)	8·0% (5·0–12·5)
Clinically significant bradycardia	2·13 (1·37–3·32)	351 (4·2%)	7·9% (3·9–15·3)
Myocardial infarction with ischaemic symptoms	3·31 (1·78–6·15)	144 (1·7%)	4·2% (1·9–9·2)
Total explained	..	..	85·5% (78·8–90·4)

Relationship between Intraoperative Mean Arterial Pressure and Clinical Outcomes after Noncardiac Surgery

Toward an Empirical Definition of Hypotension

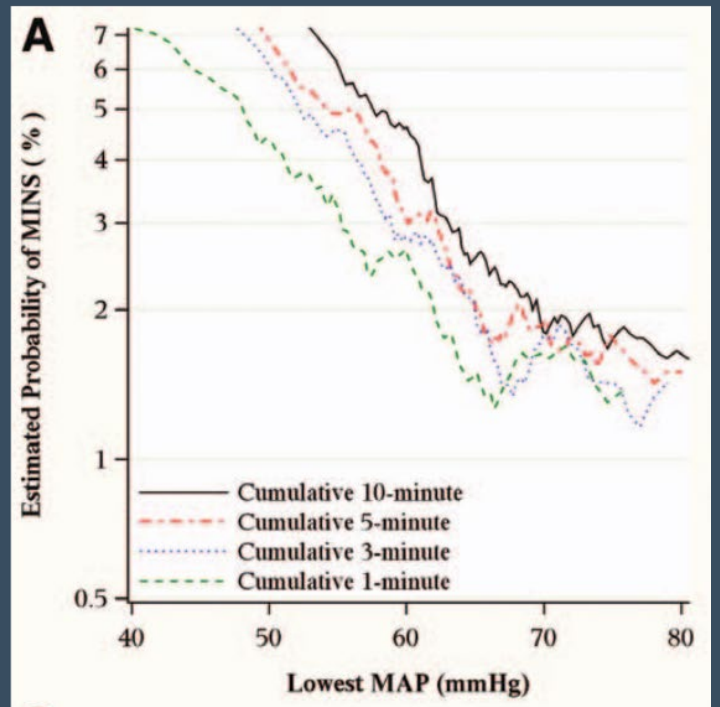
Association of Intraoperative Hypotension with Acute Kidney Injury after Elective Noncardiac Surgery

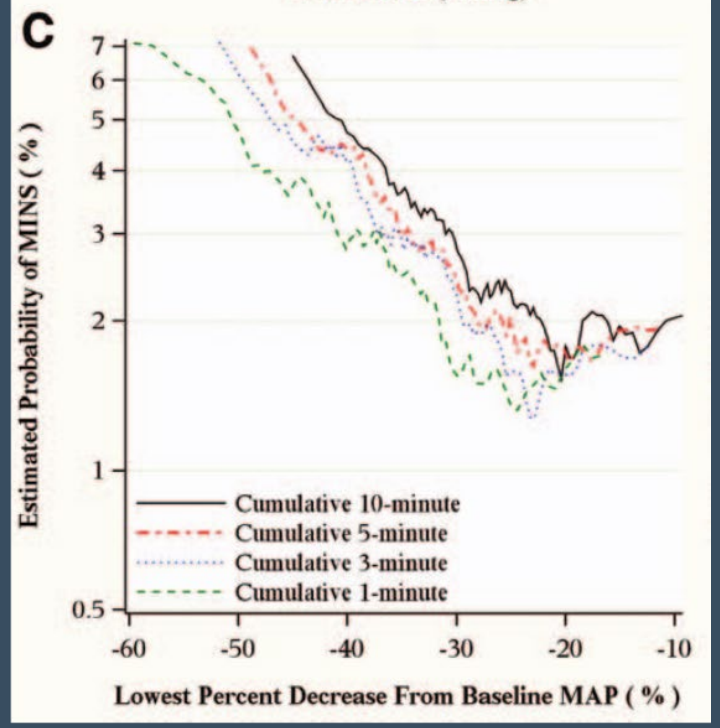
Louise Y. Sun, M.D., S.M., Duminda N. Wijeysundera, M.D., Ph.D., Gordon A. Tait, Ph.D., W. Scott Beattie, M.D., Ph.D.

Association between Intraoperative Hypotension and Hypertension and 30-day Postoperative Mortality in Noncardiac Surgery

Terri G. Monk, M.D., M.S., Michael R. Bronsert, Ph.D., M.S., William G. Henderson, M.P.H., Ph.D., Michael P. Mangione, M.D., S. T. John Sum-Ping, M.D., Deyne R. Bentt, M.D., C.P.H.I.M.S., Jennifer D. Nguyen, M.D., Joshua S. Richman, M.D., Ph.D., Robert A. Meguid, M.D., M.P.H., Karl E. Hammermeister, M.D.

Walsh, Anesthesiology, 2013
Monk, Anesthesiology 2015
Sun, Anesthesiology 2015



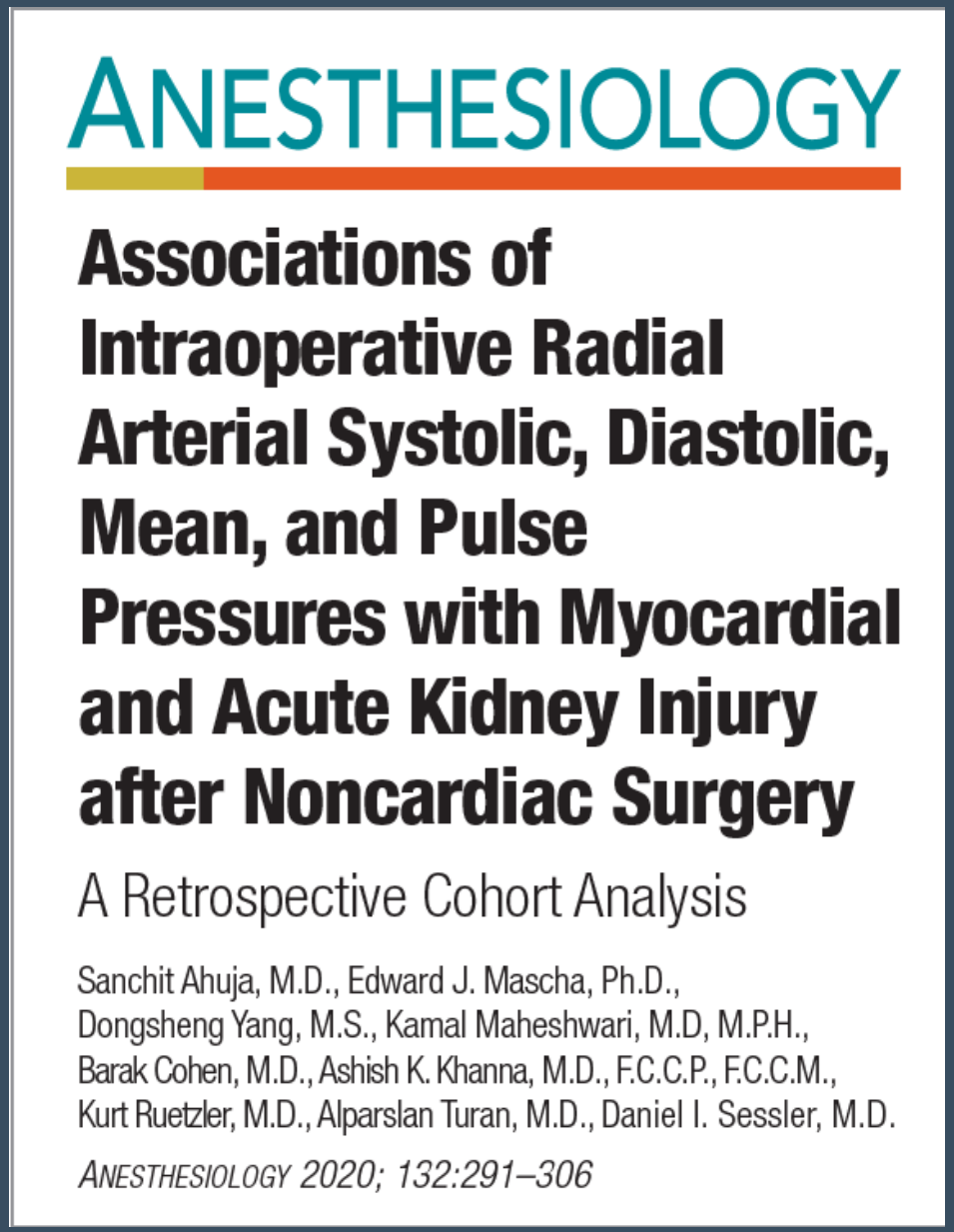


Relationship between Intraoperative Hypotension, Defined by Either Reduction from Baseline or Absolute Thresholds, and Acute Kidney and Myocardial Injury after Noncardiac Surgery

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

- Absolute MAP 65 vs. relative 20-25% MAP threshold - similar
- Baseline pressure – no interaction



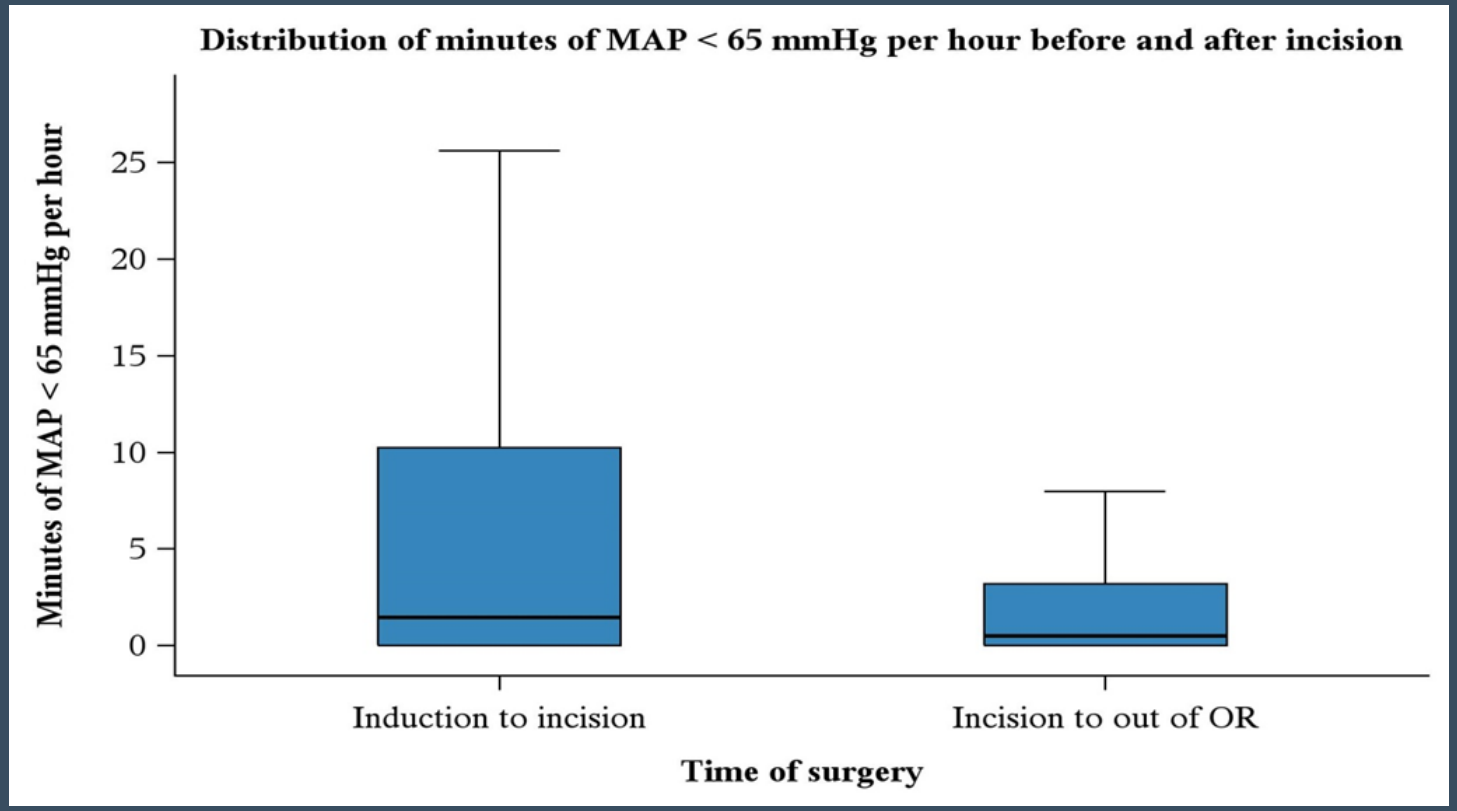
- 90 mmHg for systolic
- 65 mmHg for mean
- 50 mmHg for diastolic
- 35 mmHg for pulse pressure.

Anaesthesia 2018, 73, 1223–1228 doi:10.1111/anae.14416

Original Article

The association of hypotension during non-cardiac surgery, before and after skin incision, with postoperative acute kidney injury: a retrospective cohort analysis

K. Maheshwari,[1] A. Turan,[1] G. Mao,[2] D. Yang,[2] A. K. Niazi,[3] D. Agarwal,[4] D. I. Sessler[5] and A. Kurz[6]

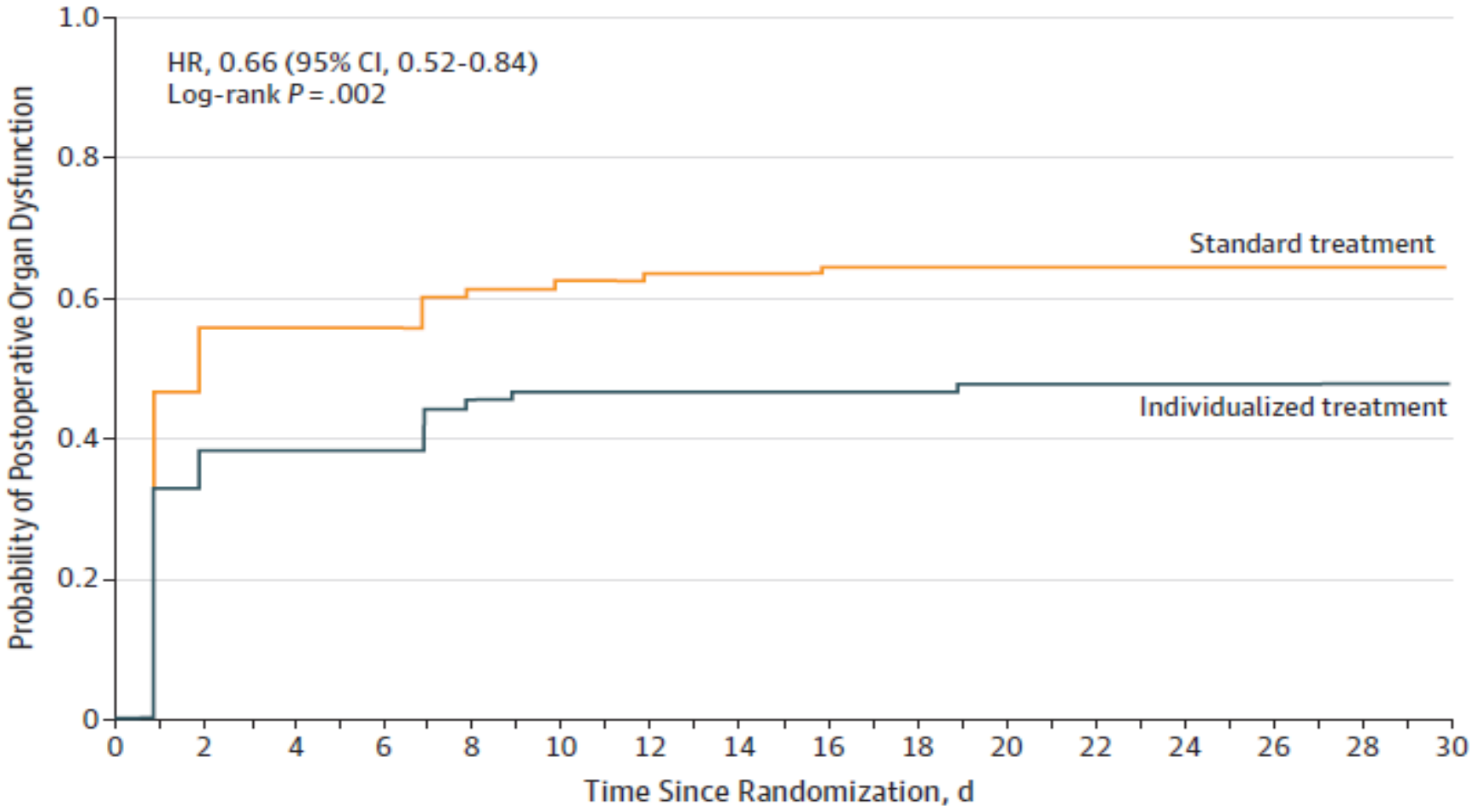


- One-third of all hypotension happened before surgery start

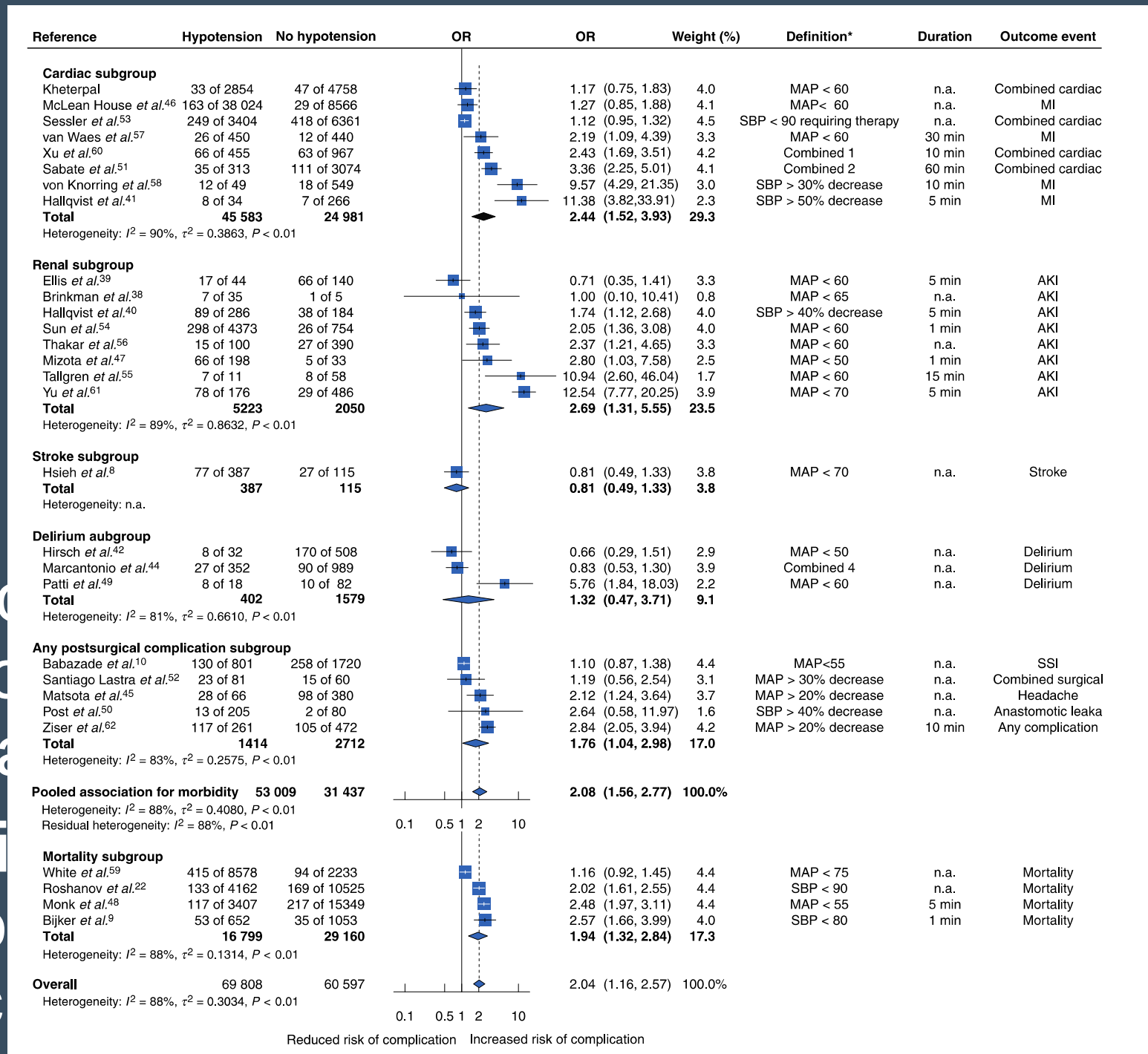
JAMA | Original Investigation | CARING FOR THE CRITICALLY ILL PATIENT

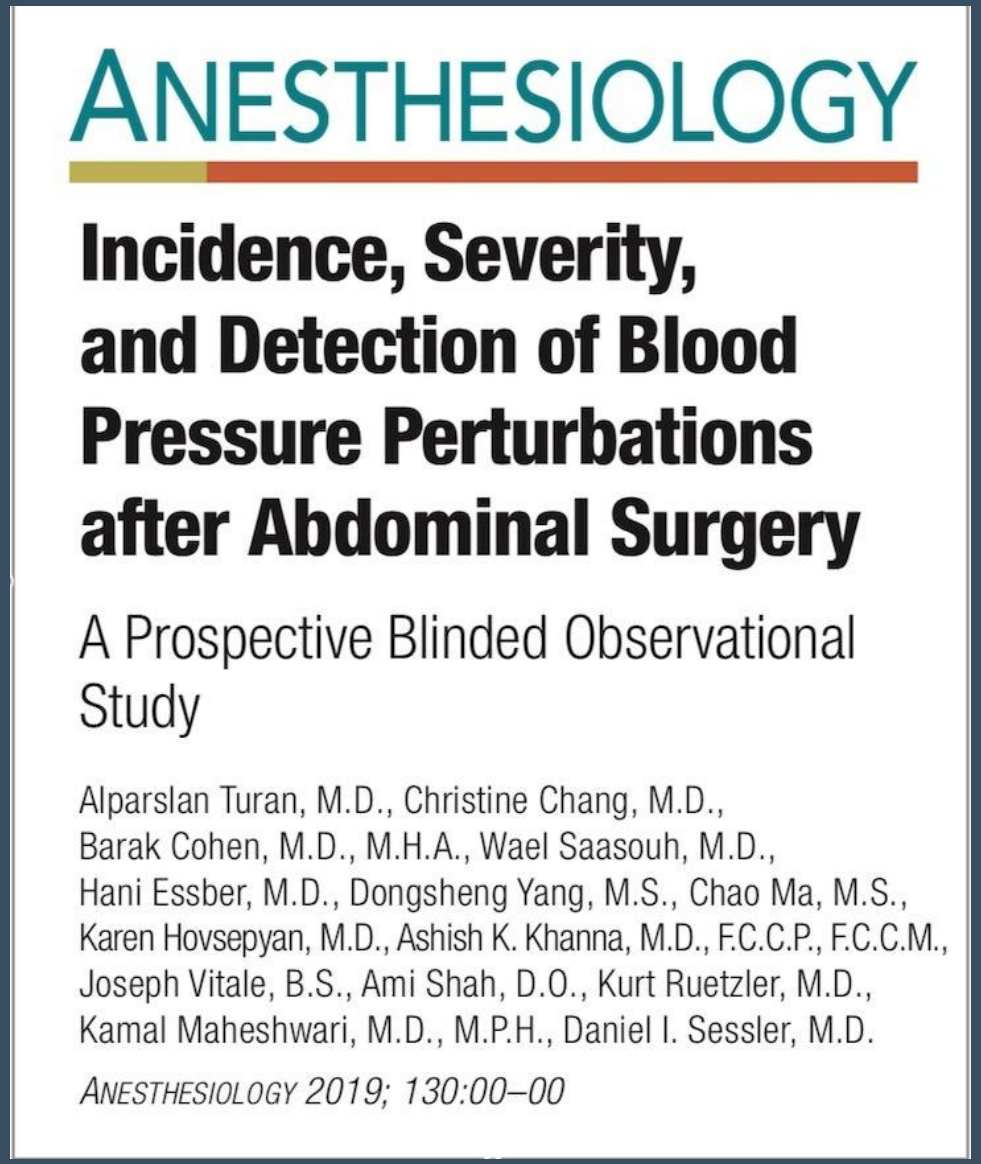
Effect of Individualized vs Standard Blood Pressure Management Strategies on Postoperative Organ Dysfunction Among High-Risk Patients Undergoing Major Surgery

A Randomized Clinical Trial



- Intrac … with
  posto … , and
  morta …
- A uni … n of
  hypo … rch into this
  topic …





ANESTHESIOLOGY

Incidence, Severity, and Detection of Blood Pressure Perturbations after Abdominal Surgery

A Prospective Blinded Observational Study

Alparslan Turan, M.D., Christine Chang, M.D., Barak Cohen, M.D., M.H.A., Wael Saasouh, M.D., Hani Essber, M.D., Dongsheng Yang, M.S., Chao Ma, M.S., Karen Hovsepyan, M.D., Ashish K. Khanna, M.D., F.C.C.P., F.C.C.M., Joseph Vitale, B.S., Ami Shah, D.O., Kurt Ruetzler, M.D., Kamal Maheshwari, M.D., M.P.H., Daniel I. Sessler, M.D.

ANESTHESIOLOGY 2019; 130:00–00

- Both hypotension and hypertension are common, prolonged, and profound in surgical wards.
- Often missed by routine intermittent monitoring.

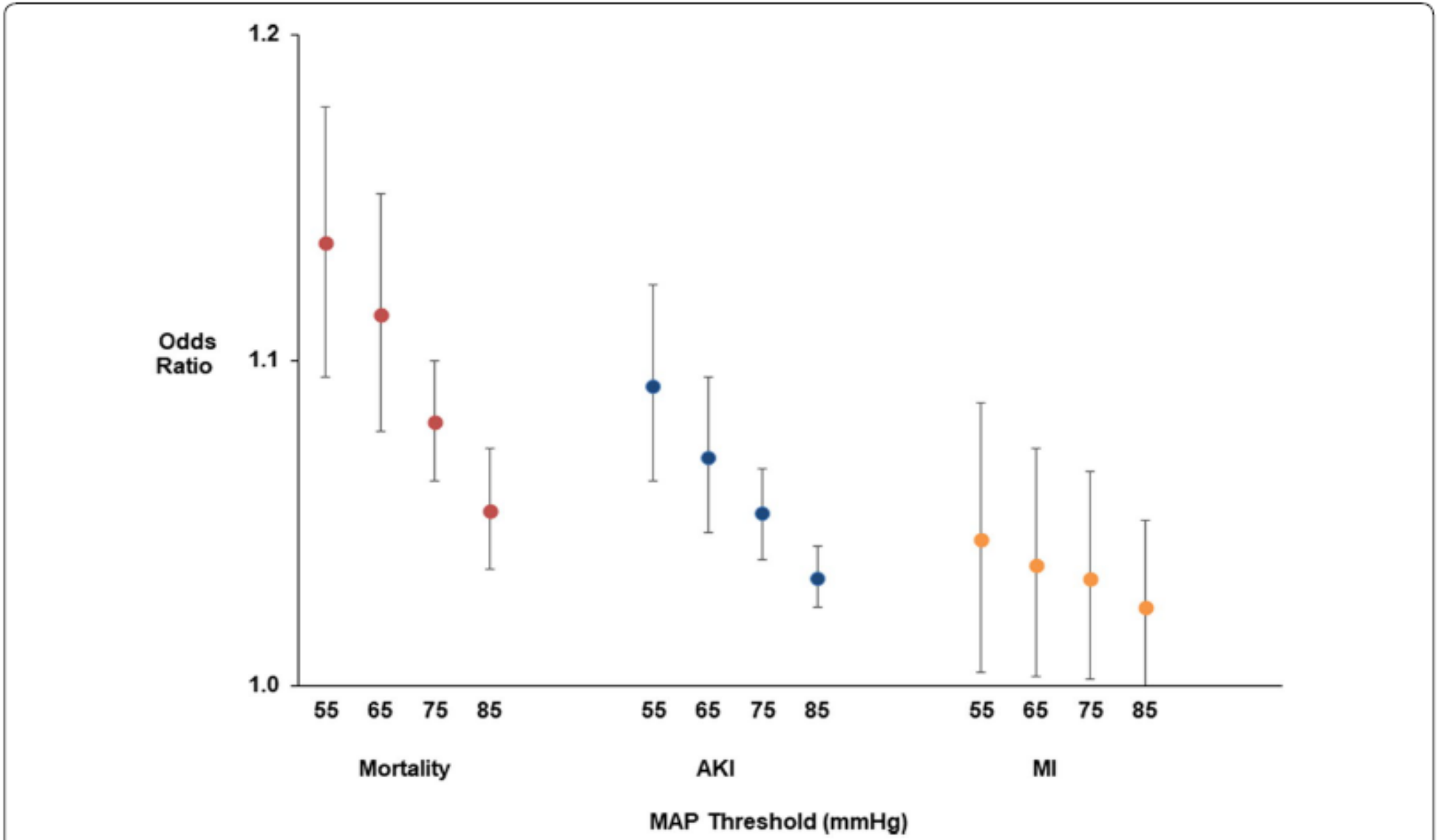


Fig. 2 Association of hypotension exposure with in-hospital mortality, AKI and myocardial injury. Adjusted odds ratios and 95% confidence intervals for a 1 mmHg increase in TWA-MAP, below different thresholds are shown for the primary outcome of in-hospital mortality and secondary outcomes of acute kidney injury and myocardial injury

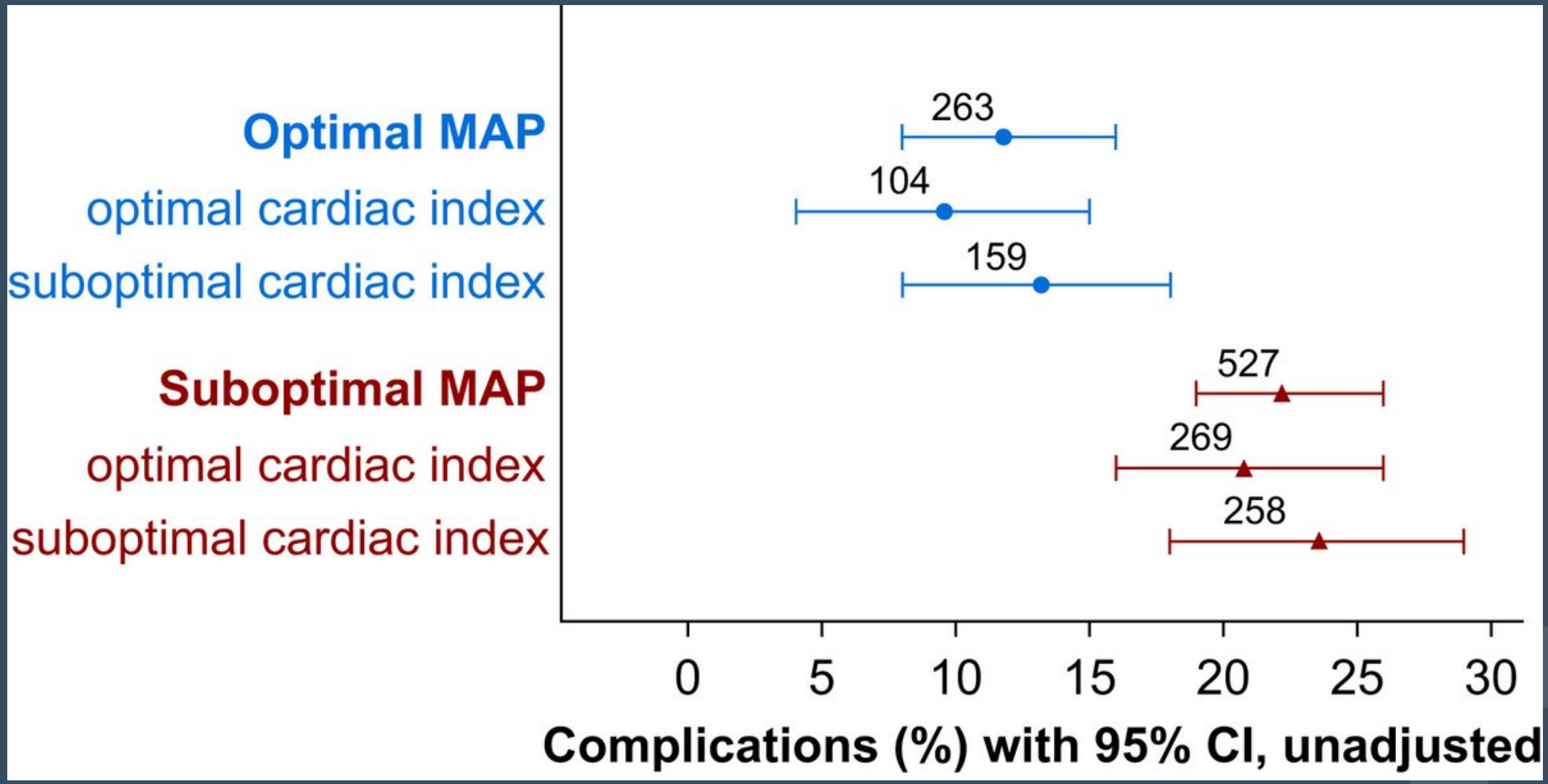
–867
https://doi.org/10.1186/s13054-018-5218-5

Organ perfusion and cardiac output

- Are we ignoring the cardiac output?
- Between CO or MAP which is more important?

- CO = (MAP – CVP)/ SVR

$$F = \frac{\pi \Delta P r^4}{8 \eta l}$$



Maheshwari, BJA, 2021

JOURNAL OF MEDICAL ECONOMICS
https://doi.org/10.1080/13696998.2019.1591147
Article 0013-FT.R1/1591147

Taylor & Francis
Taylor & Francis Group

ORIGINAL RESEARCH

OPEN ACCESS

Check for updates

Hospital costs associated with intraoperative hypotension among non-cardiac surgical patients in the US: a simulation model

Eric L. Keuffel[a], John Rizzo[b], Mitali Stevens[c], Candace Gunnarsson[d] and Kamal Maheshwari[e]

[a]Health Finance & Access Initiative, Bryn Mawr, PA, USA; [b]Stony Brook University Medical Center, Stony Brook University (New York), Stony Brook, NY, USA; [c]Edwards Lifesciences, Irvine, CA, USA; [d]Gunnarsson Consulting, Jupiter, FL, USA; [e]Cleveland Clinic, Cleveland, OH, USA

- The model results suggest improved intraoperative hypotension control in a hospital (10,000 surgery) is associated with mean cost reductions ranging from $1.2–$4.6 million per year.

JOURNAL OF MEDICAL ECONOMICS
2019, VOL. 22, NO. 4, 383–389
https://doi.org/10.1080/13696998.2019.1576695
Article 0216-FT.R1/1576695

Taylor & Francis
Taylor & Francis Group

ORIGINAL RESEARCH

A Monte Carlo simulation estimating US hospital cost reductions associated with hypotension control in septic ICU patients

Eric L. Keuffel[a], Mitali Stevens[b], Candace Gunnarsson[c], John Rizzo[d], Daniel I. Sessler[e] and Kamal Maheshwari[e]

[a]Health Finance & Access Initiative, Chester, PA, USA; [b]Edwards Lifesciences, Irvine, CA, USA; [c]Gunnarsson Consulting, Jupiter, FL, USA; [d]Department of Family, Population and Preventive Medicine, Program in Public Health, Stony Brook University, Stony Brook, NY, USA; [e]Cleveland Clinic, Cleveland, OH, USA

- Hospital with1,000 annual sepsis cases in the ICU would save
- $417,000 per year based on a 5-mmHg increase (95% CI: $187,000–$696,000) and $600,000 per year for a 10-mmHg increase (95% CI:$268,000–$1,046.000).

Key message

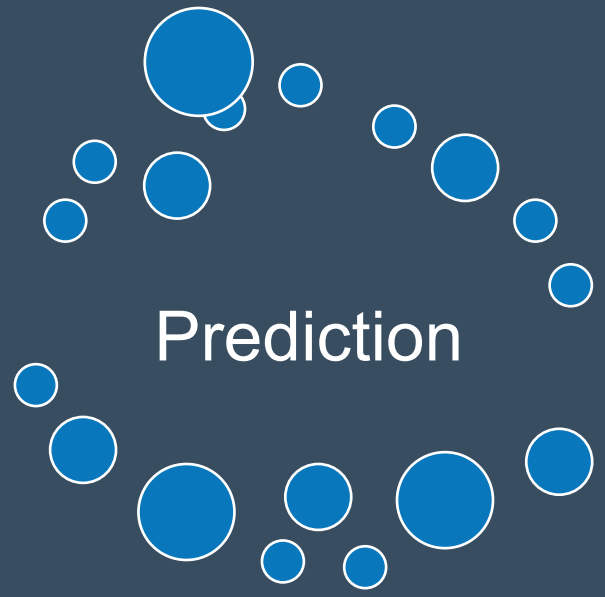
- Hypotension is associated with kidney injury, myocardial injury, delirium, and mortality, therefore should be avoided
  - *To maintain organ perfusion*
  - *To avoid complications*
  - *To optimize the quality of care*
  - *To optimize cost*

POISE Trial, Lancet 2008
Futier, JAMA 2017; INPRESS Trial
Salmasi, Anesthesiology 2017
Maheshwari, A&A, 2019

How do we prevent hypotension?

Team effort

Maheshwari et al, Anesthesia and Analgesia, 2022



Early diagnosis

Treatment

Input

Algorithm

Output

Hemodynamic state

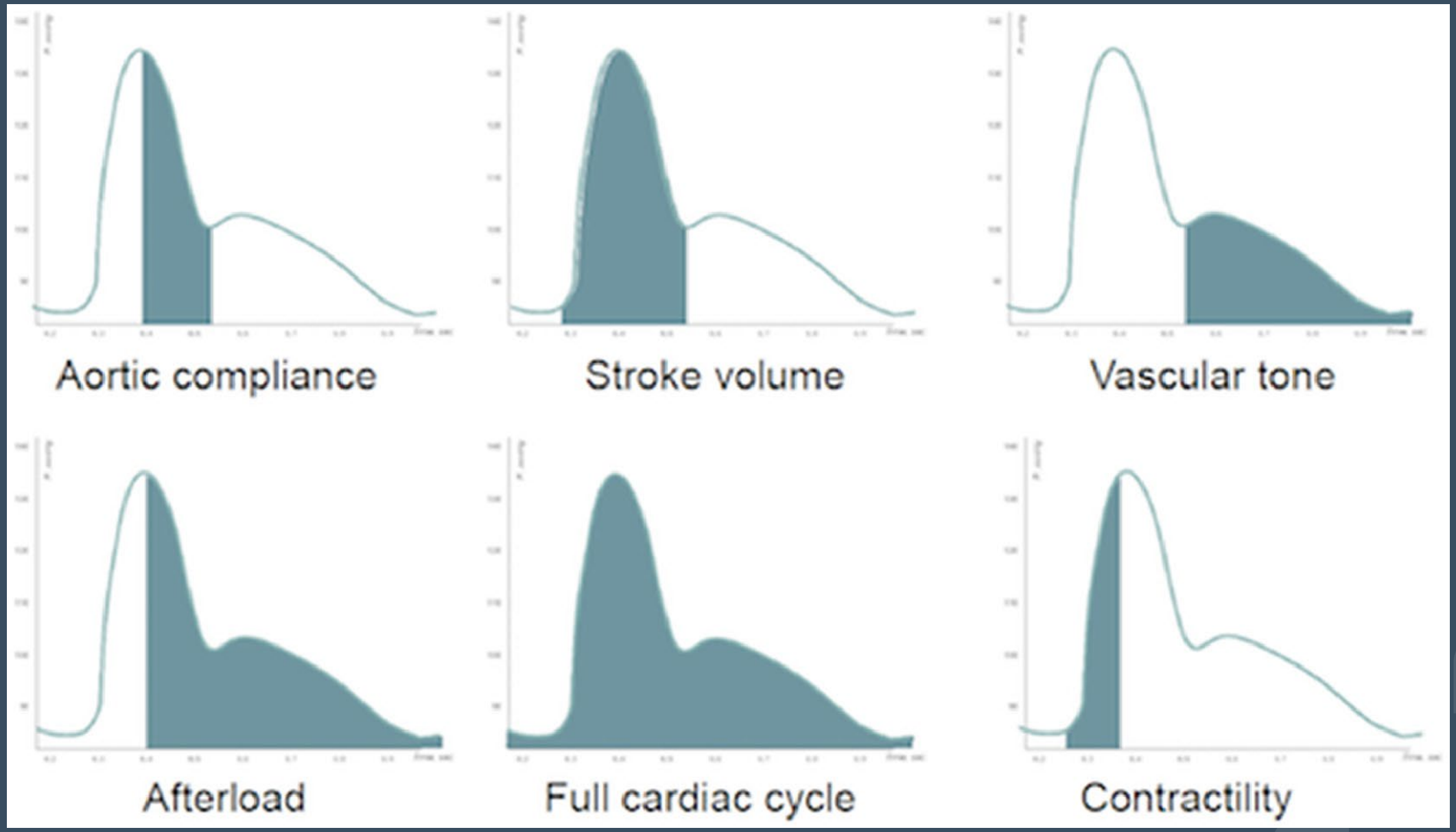
Suggested Intervention

Blood pressure: the input data

Intermittent : Oscillometric

Continuous: Invasive

Non-invasive



Awadallah, JCVA, 2021

Advanced hemodynamic parameters

Venous or tissue oximetry	Cardiac output	Pre-load		Afterload
SvO2	CO	SVV	GEDI	SVR / SVRI
StO2	CI	PPV	CVP	Eadyn
ScvO2	SV	RVEDV	PASP/PADP	PVR/ PVRI
	SVI	GEDI	PAOP	

Contractility	Lung water	Blood pressure	Predictive
dP/dt	EVLW	SBP	HPI
EF	EVLWI	DBP	AFM
Echocardiography		MAP	
Pressure volume graphs		PP	

Blood pressure measurement

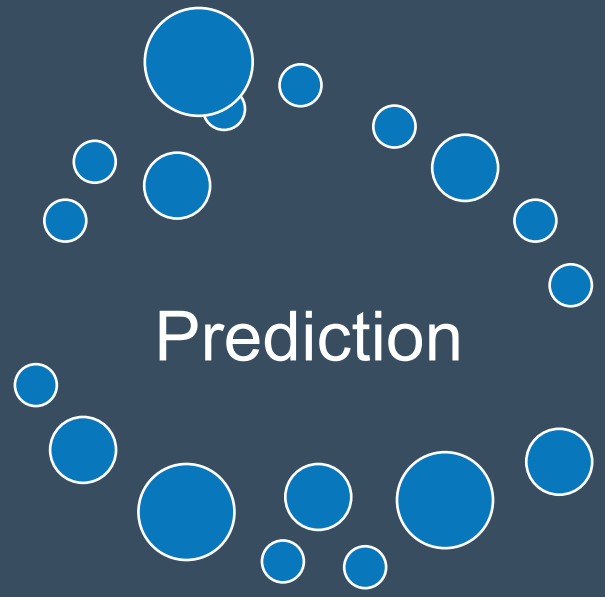
Intermittent

- Valid mean arterial pressure
  - Systolic and diastolic are derived parameters
- Intermittent
- Lack advanced hemodynamic parameters
- Lack prediction parameters

Continuous

- Continuous invasive or noninvasive arterial pressure monitoring can reduce hypotension

Maheshwari, Anesthesia and Analgesia, 2018
Michard, Intensive care medicine, 2018
Naylor, Anesthesia and Analgesia 2019



Early diagnosis

Treatment

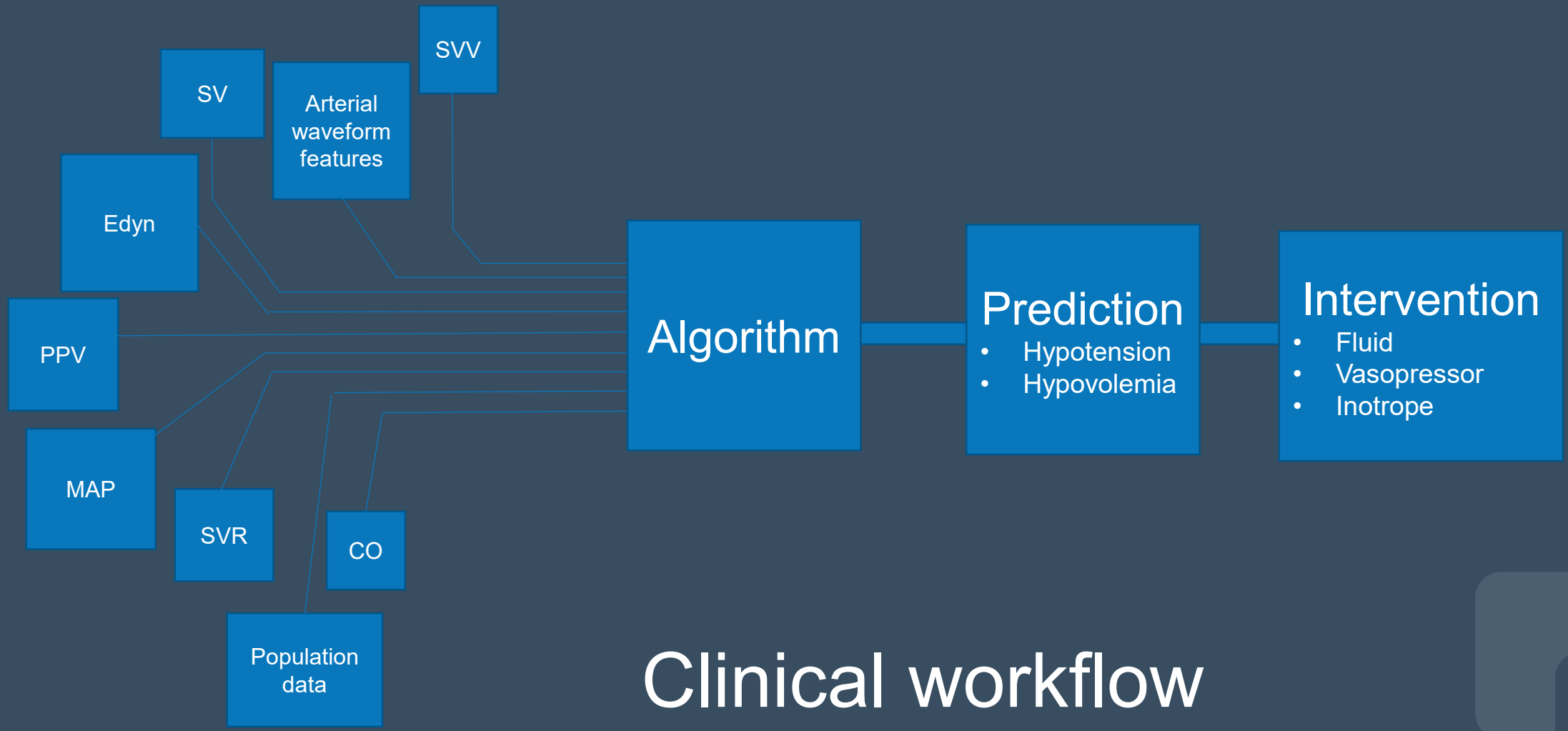
Input

Algorithm

Output

Hemodynamic state

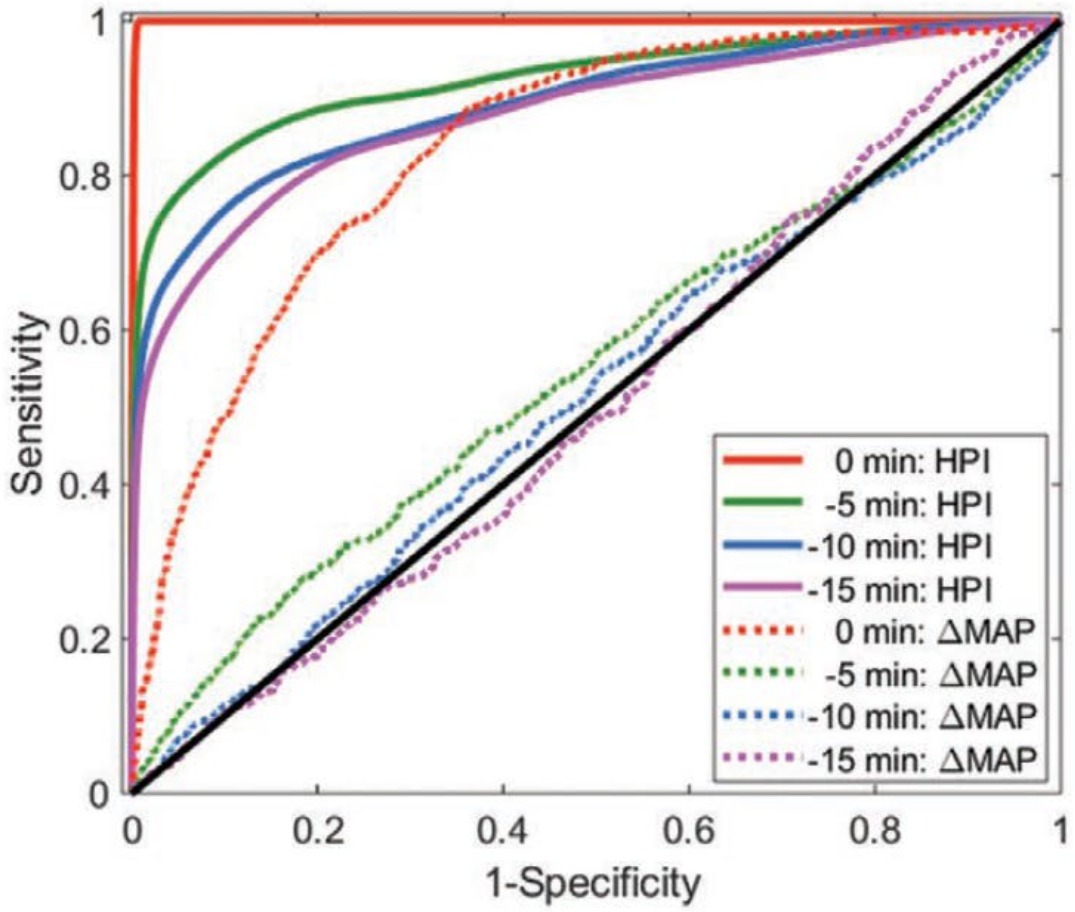
Suggested Intervention



Clinical workflow

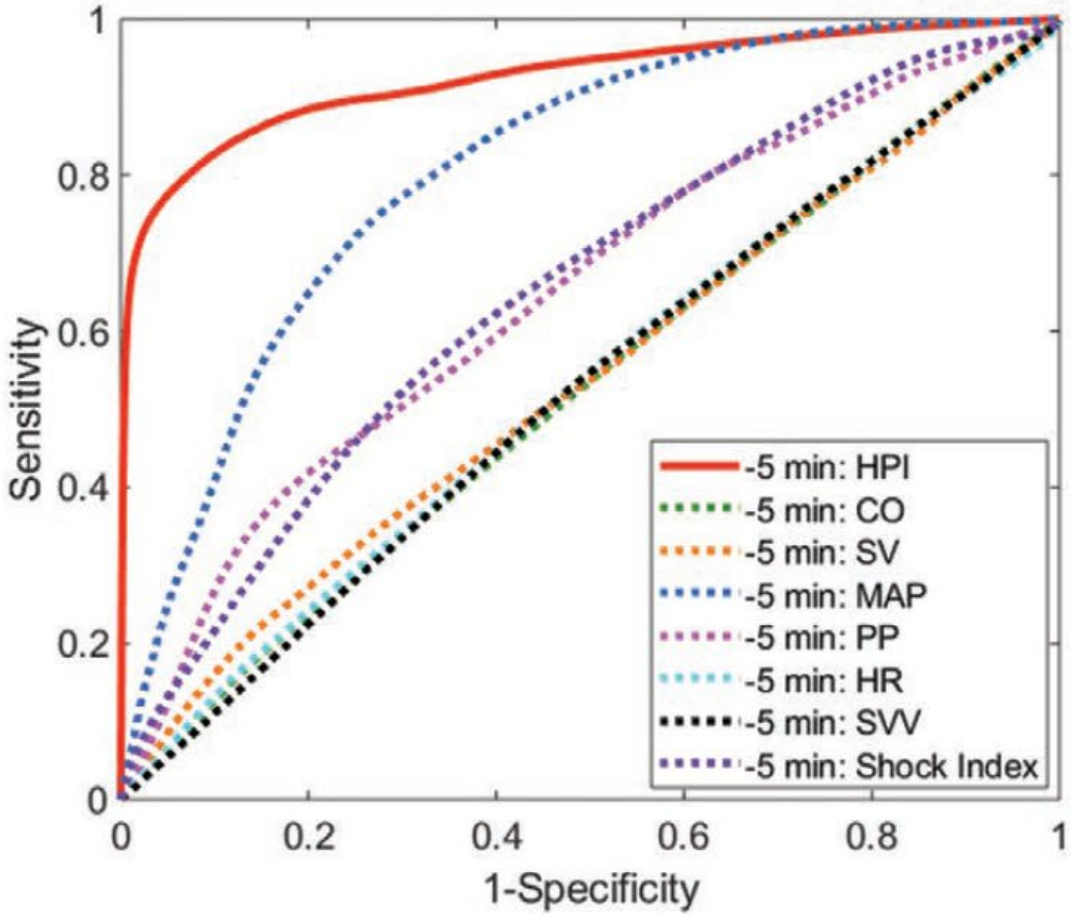
Prediction of Hypotension 5 Minutes Before the Event

Receiver operating characteristic curves for the ability of the Hypotension Prediction Index to predict hypotension at 5



Prediction of Hypotension 10 Minutes Before the Event

Receiver operating characteristic curves for the ability of the Hypotension Prediction Index to predict hypotension at 10



Davies, Anesthesia and Analgesia 2019

HPI evaluation trials

Effect of a Machine Learning–Derived Early Warning System for Intraoperative Hypotension vs Standard Care on Depth and Duration of Intraoperative Hypotension During Elective Noncardiac Surgery
The HYPE Randomized Clinical Trial

Marije Wijnberge, MD; Bart F. Geerts, MD, PhD, MSc, MBA; Liselotte Hol, MD; Nikki Lemmers, MD; Marijn P. Mulder, BSc; Patrick Berge, MD; Jimmy Schenk, MSc; Lotte E. Terwindt, MD; Markus W. Hollmann, MD, PhD; Alexander P. Vlaar, MD, PhD, MBA; Denise P. Veelo, MD, PhD

- HPI multicenter study
- SMART BP trial

ANESTHESIOLOGY

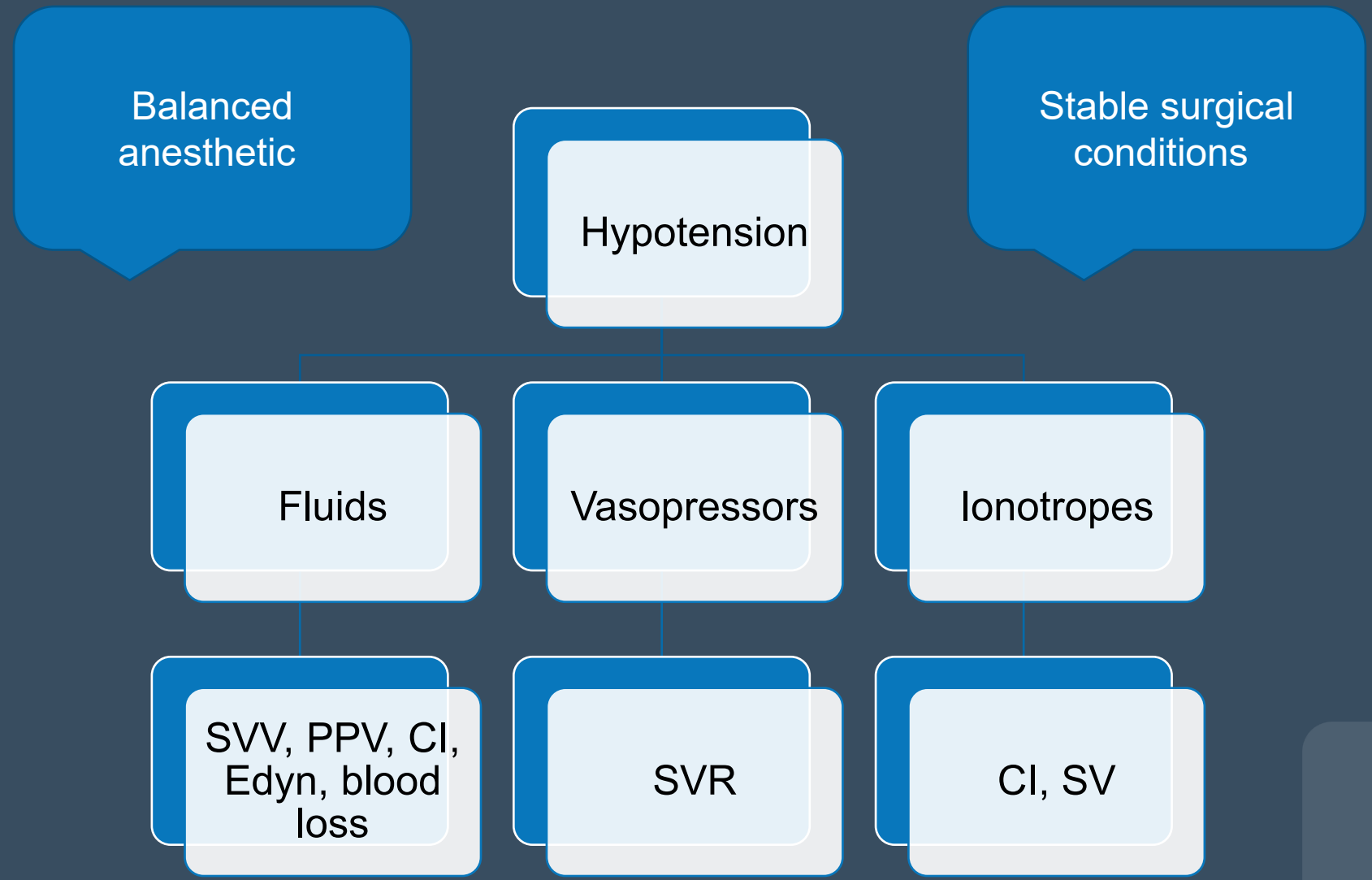
Hypotension Prediction Index for Prevention of Hypotension during Moderate- to High-risk Noncardiac Surgery

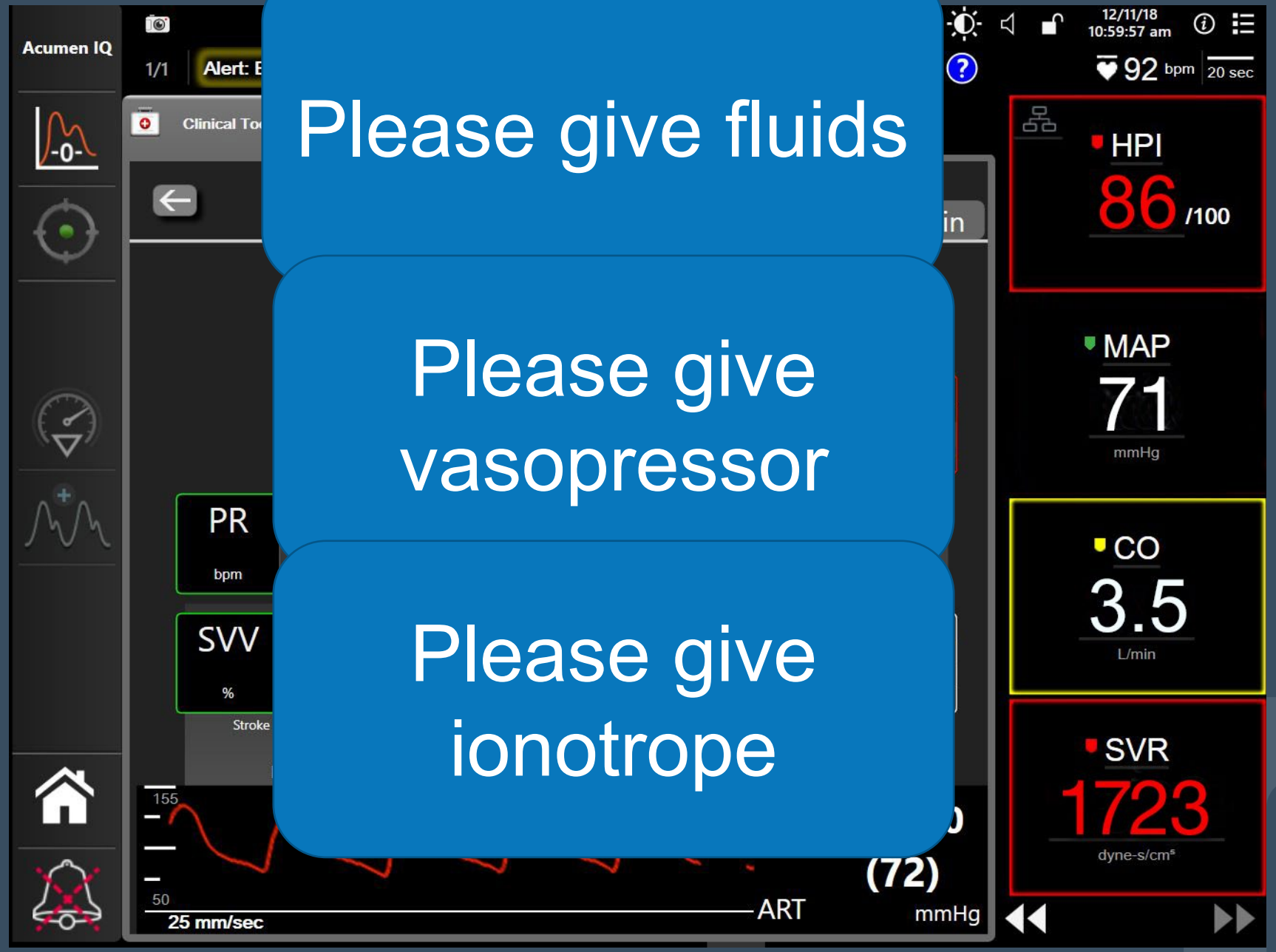
A Pilot Randomized Trial

Kamal Maheshwari, M.D., M.P.H., Tetsuya Shimada, M.D., Ph.D., Dongsheng Yang, M.S., Sandeep Khanna, M.D., Jacek B. Cywinski, M.D., Samuel A. Irefin, M.D., Sabry Ayad, M.D., Alparslan Turan, M.D., Kurt Ruetzler, M.D., Yuwei Qiu, M.D., Partha Saha, M.D., Edward J. Mascha, Ph.D., Daniel I. Sessler, M.D.

ANESTHESIOLOGY 2020; XXX:00–00

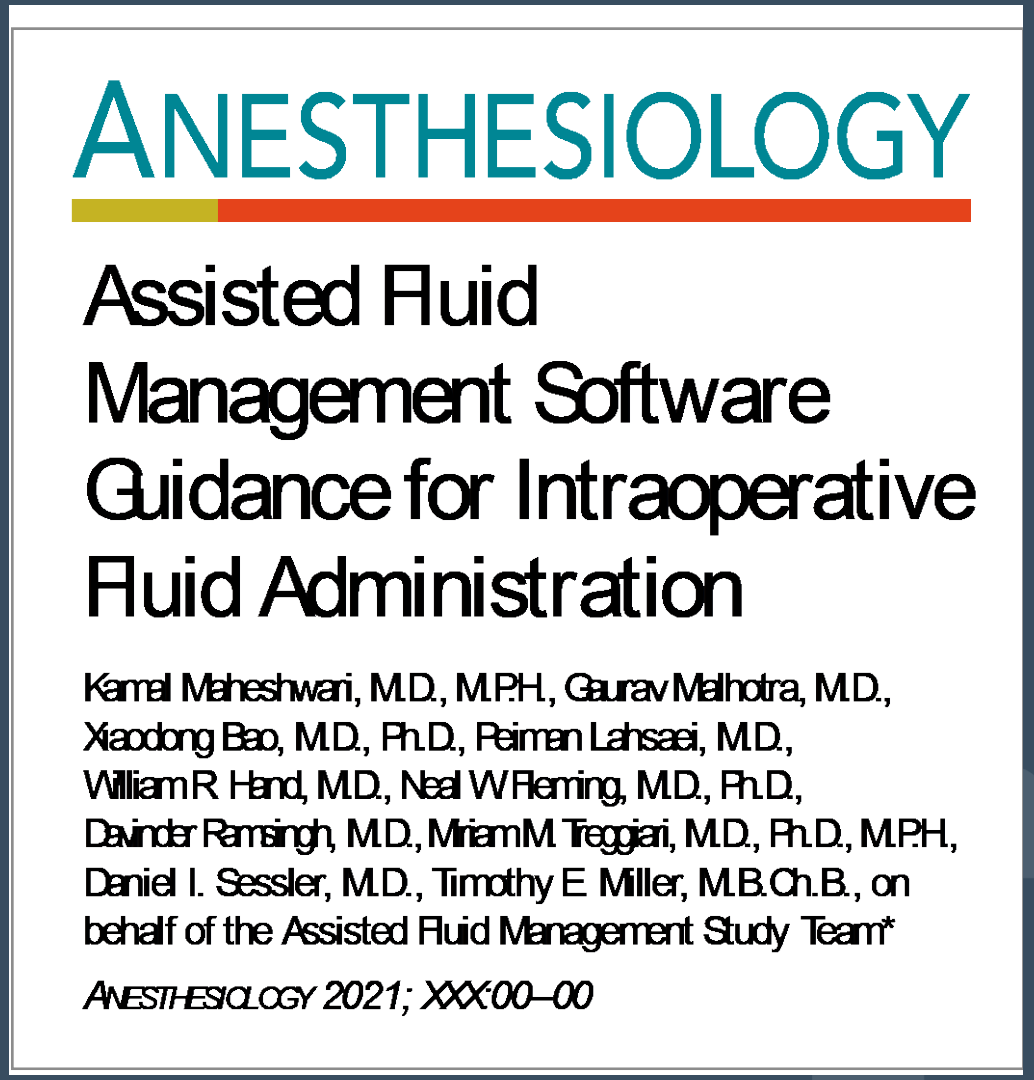
Appropriate treatment


Balanced anesthetic
Hypotension
Stable surgical conditions
Fluids
Vasopressors
Ionotropes
SVV, PPV, CI, Edyn, blood loss
SVR
CI, SV


Please give fluids
Please give vasopressor
Please give ionotrope
Acumen IQ
12/11/18
10:59:57 am
92 bpm
20 sec
HPI
86 /100
MAP
71
mmHg
CO
3.5
L/min
SVR
1723
dyne-s/cm⁵
PR
bpm
SVV
%
Stroke
155
50
25 mm/sec
ART
(72)
mmHg

AFM is Effective and Safe

- AFM recommended and completed bolus led to around 60% increase in stroke volume compared to



ANESTHESIOLOGY

Assisted Fluid Management Software Guidance for Intraoperative Fluid Administration

Kamal Maheshwari, M.D., M.P.H., Gaurav Malhotra, M.D., Xiaodong Bao, M.D., Ph.D., Peiman Lahsaei, M.D., William R. Hand, M.D., Neal W. Fleming, M.D., Ph.D., Davinder Ramsingh, M.D., Miriam M. Treggiari, M.D., Ph.D., M.P.H., Daniel I. Sessler, M.D., Timothy E. Miller, M.B.Ch.B., on behalf of the Assisted Fluid Management Study Team*

ANESTHESIOLOGY 2021; XXX:00–00

Vasopressor use

- Systemic vascular resistance SVR
  - Difficult to measure
- Dynamic elastance Edyn
  - defined as the PPV/SVV ratio, accurately predicts the arterial pressure response after volume administration in hypotensive, preload-dependent patients with acute circulatory failure.
  - < 0.89 will not increase MAP with volume expansion

Monge Garcia, Critical care, 2011

Inotrope use

- Cardiac contractility
  - LV contractility via echocardiography
  - Cardiac output trends
  - dP/dt from arterial pressure waveform
    - combined interaction of the LV ejection and the arterial system properties

Monge Garcia, Critical Care, 2018

Future

- SMART BP trial
- Decision support systems
- Direct organ perfusion sensors
  - Microdialysis
  - CO_2 sensors

Summary

- Hypotension is associated with kidney injury, myocardial injury, delirium, mortality and should be avoided
- Hypotension reduction strategies include
  - Continuous invasive or noninvasive blood pressure monitoring
  - Hypotension prediction and appropriate treatment algorithms

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