Hemodynamic Management

Peri- OP & ICU Algorithms

This document is intended to provide information to an international audience outside of the US.

GETINGE

Abbreviations

CI	Cardiac Index	PAP	Pulmonary Artery Pressure
CVC	Central Venous Catheter	PAC	Pulmonary Artery Catheter
CVP	Central Venous Pressure	PaO_2	Arterial Partial Pressure of Oxygen
DO_2I	Oxygen Delivery Index	PCWP	Pulmonary Capillary Wedge Pressure
EEO	End-Expiratory Occlusion	PeriOP	Perioperative
ELWI	Extravascular Lung Water Index	PLR	Passive Leg Raising
FiO_2	Fraction of inspired Oxygen	PPV	Pulse Pressure Variation
GDT	Goal Directed Therapy	RM	Recruitment Maneuver
GEDI	Global Enddiastolic Volume Index	SaO_2	Arterial Oxygen Saturation
Hb	Haemoglobin	$ScvO_2$	Central Venous Oxygen Saturation
HES	Hydroxyethyl starch	SvO_2	Venous Oxygen Saturation
HR	Heart Rate	SROC	Summary Receiver Operating Characteristic
ICU	Intensive Care Unit	SV	Stroke Volume
LoS	Length of Stay	SVRI	Systemic Vascular Resistance Index
MAP	Mean Arterial Pressure	SVV	Stroke Volume Variation
O_2ER	Oxygen Extraction Ratio		

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Goal Directed Therapy

In 1988 Shoemaker developed the first principles of goal directed therapy (GDT) and reported on its superiority regarding outcome[1].

This concept has been adopted ever since and new perioperative indications such as general, abdominal, cardiac and orthopaedic surgery have evolved. Improved outcome through GDT has been proven in many publications.

Algorithms or standard operating procedures (SOP) have become more and more important in the daily business of physicians and nurses worldwide.

They are the key tools to translate the concept of GDT into clinical practice. This algorithm booklet is intended to give an overview of published procedures and algorithms in the perioperative and ICU setting and to support health care specialists to choose the right approach for their patients.
It is not intended to instruct or dictate any medical advice.
The treating physician is responsible for determining and utilising the appropriate diagnostic and therapeutic measures for each individual patient.

What is a perfect algorithm?

A perfect haemodynamic optimisation algorithm has to include multiple parameters and answer the following questions:

	Relevant Parameters
Is oxygen delivery sufficient?	DO_2I, SaO_2, Hb, CI
Is Cardiac Index and Stroke Volume sufficient and stable?	CI, SV
Is the patient fluid responsive and preload optimised?	SVV and PPV, GEDI
Is lung water elevated?	ELWI
Is perfusion pressure sufficient?	MAP
What is the vascular tone?	SVRI
What is the tissue oxygen balance?	$ScvO_2$, SvO_2, O_2ER, Lactate

General information

Dos and Don‘ts for algorithms

Do`s

- Individualise for different indications and patient groups
- Include parameters that give information about oxygen delivery and consumption
- Easy and simple to follow

Don‘ts

- Base it on parameters that have been proven to be inadequate for preload assessment e.g. CVP, PCWP
- Specify which type of fluid to give: colloids, crystalloids, HES, etc.
- Specify which type of inotrope / vasopressor to give: adrenaline, noradrenaline, dobutamine, etc.

Which algorithm to choose?

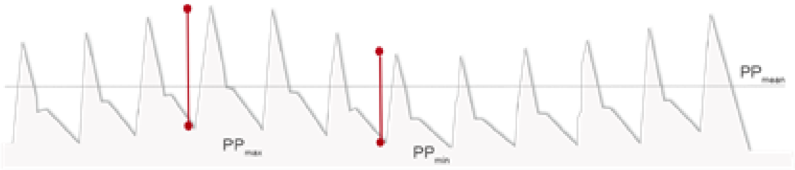
All published algorithms can be clustered by their main target parameters and their haemodynamic approach to increase the CI.

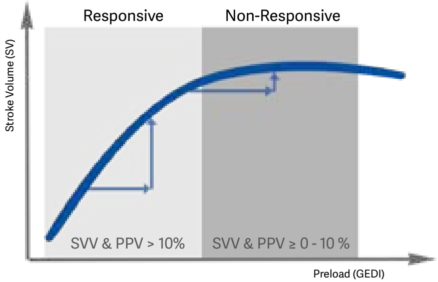
CI optimisation	Peri-OP: Getinge Peri-OP	NICE /SFAR	Benes	Salzwedel	Goepfert	Pearse	Donati	Habicher	ICU: Getinge ICU	Oldenburg	Saugel
a) With fluids:											
Based on fluid responsiveness parameters	√		√	√	√		√	√		√	
Based on fluid challenge	√	√			√	√	√	√			√
Based on GEDI optmisation					√		√		√		√
b) With inotropes	√		√	√	√	√	√		√	√	√
Target Parameters	CI GEDI ELWI	SV	CVP CI	PPV CI MAP	GEDI ELWI CI MAP	SV DO_2I	O_2ER CVP	SV	CI GEDI ELWI	CI SvO_2 MAP	CI GEDI ELWI

Stroke Volume Variation / Pulse Pressure Variation

Stroke Volume Variation (SVV)

Pulse Pressure Variation (PPV)





- Easy and simple parameter
- Reliable indicator for fluid responsiveness with strongest evidence level[(2)]

- Only applicable in fully mechanically ventilated patients
- Further limitations:
  - Arrhythmias
  - Low tidal volume, Vt < 7 ml/kg
  - Poor lung compliance
  - Open chest surgery
  - Increassed abdominal pressure

Passive Leg Raising (PLR) Test

START: Monitor CI

↓

Perform PLR:
Note CI_{max} (approx. after 1 min.)

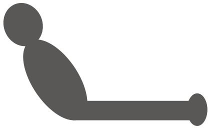
↓

ΔCI > +10%

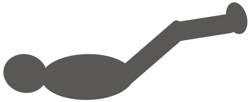
↓ YES

Patient is fluid responsive

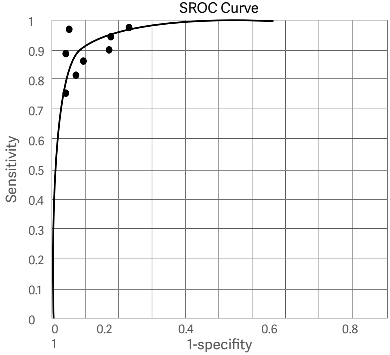
Patient is in semi-recumbent position



Limbs raised 45°, trunk in supine position



Based on (3)



PLR is a reliable test to determine fluid responsiveness with strong sensitivity and specificity[(4)].

- Easy and simple
- Endogenous volume challenge which is 100% reversible
- Independent of ventilation mode, lung compliance, cardiac rhythm and measurement technique

- Does not work well in patients with intraabdominal pressure

End-expiratory Occlusion (EEO) Test

START: Monitor CI

↓

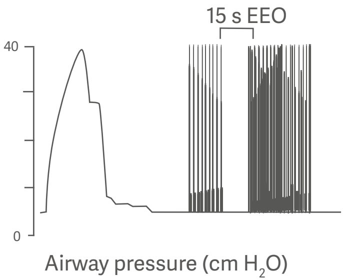
End-expiratory occlusion for 15 seconds

↓

ΔCI > 5%

YES ↓

Patient is fluid responsive

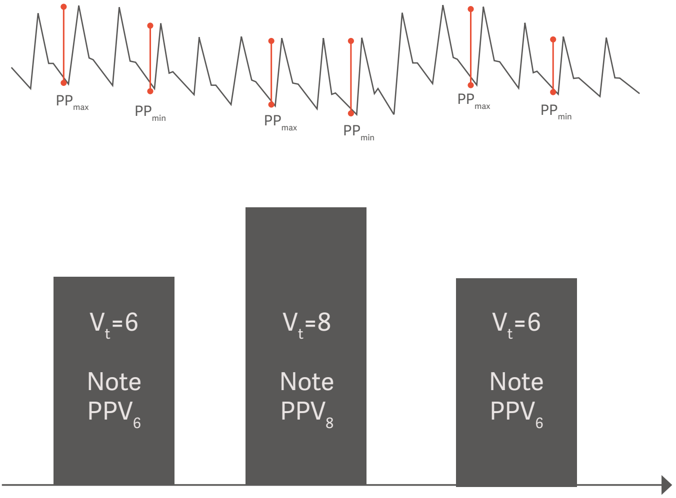


Based on (5)

Discipline	Medical intensive care unit
Publication	Monnet X et. al
Type of study	Prospective study
n	34
Inclusion criteria	inadequate tissue perfusion, unable to interrupt EEO
Centers	Hôpitaux Universitaires Paris-Sud, Paris, France
Parameters	MAP, CI
Outcome	Volume expansion increased cardiac index by >15% (2.4 +/- 1.0 to 3.3 +/- 1.2 L/min/m2, $p < 0.05$) in 23 patients (“responders”)

- ⊕ Easy and simple
- ⊕ Independent of cardiac rhythm and spontaneous breathing
- ⊖ Significant spontaneous breathing activities can interrupt the test

Tidal Volume challenge



PPV_8 - PPV_6 = > 3,5% -> Patient is fluid responsive

Based on (6)

Discipline	Medical-surgical ICU
Publication	Myatra et.al
Type of study	Prospective, single-arm study
n	20
Indications	low V_t ventilation
Inclusion criteria	controlled ventilation, no spontaneous breathing, continuous CO monitoring
Parameters	PPV, SVV, CI
Outcome	The changes in PPV or SVV during transiently increasing tidal volume (tidal volume challenge) are superior to PPV/SVV during low tidal volume ventilation

- (+) Easy and simple
- (+) Increases reliability to predict fluid responsiveness during low tidal volume ventilation
- (+) Applicable even in resource-limited settings (no cardiac output monitor required)

- (−) Limitations in patients with spontaneous breathing, cardiac arrhythmias, open chest and raised intra-abdominal pressure

Lung Recruitment Maneuver (RM)

Vt: 6-8 ml/kg
PEEP: 5 cm H_2O

↓

Note SV_T

↓

Perform Lung RM
Note SV_{LRM}

↓

$SV_{LungRM} - SV_T = \Delta SV$
$\Delta SV > 30\%$

YES ↓

Patient is fluid responsive

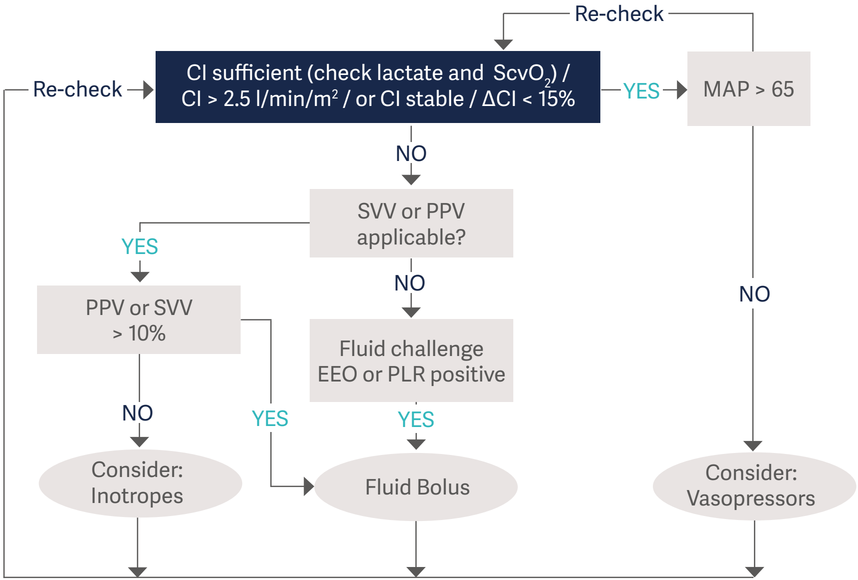
Based on (7)

Discipline	Anesthesiology
Publication	Biais et. al.
Type of study	Interventional
n	28
Indications	ventilated patients with low tidal volume
Inclusion criteria	mechanically ventilated patients in OR
Centers	Bordeaux, University Hospital, France
Parameters	SV, HR, MAP, PPV
Outcome	stroke volume decrease during lung recruitment maneuver could predict preload responsiveness

- ⊕ Easy and simple
- ⊕ Can be used in case of low tidal volume ventilation
- ⊕ Even more accurade than conventional PPV

- ⊖ Not tested in patients suffering from arrhythmia, right and/or left heart failure, lung disease, obesity or receiving vasopressors and/or inotropes
- ⊖ Only tested with patients, shortly after induction of anesthesia

Getinge Peri-OP Algorithm



Developed by PULSION Medical Systems with experts from the medical advisory board

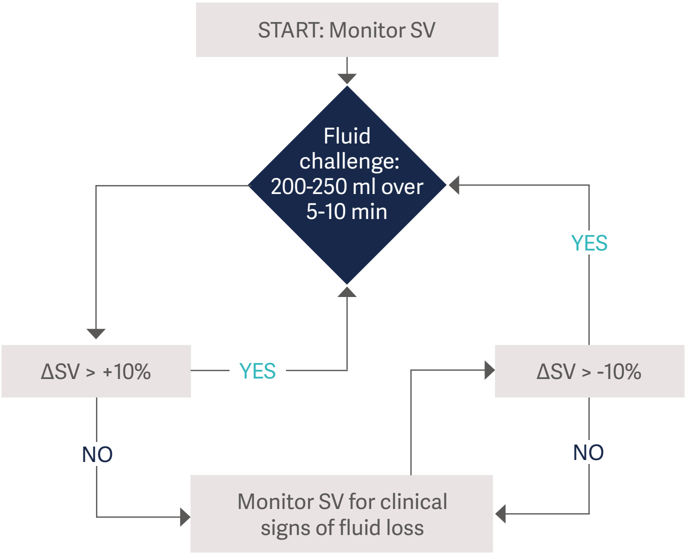
Additionally the following should be considered :

Is cardiac output adequate ?	• Check also $ScvO_2$, Lacate, ΔPCO_2v-a and clinical signs of hypoperfusion
Definition fluid challenge:	• Choose target value of SV or SVI change • Administer fluid bolus and check if SV or SVI increases
Are there warning parameters for volume overload?	• Check for clinical signs of hypoperfusion

- (+) Includes fluid responsiveness
- (+) Considers use of inotropes
- (+) Includes perfusion pressure

- (−) Complex algorithm

NICE (UK) / SFAR (France) Guideline Algorithm



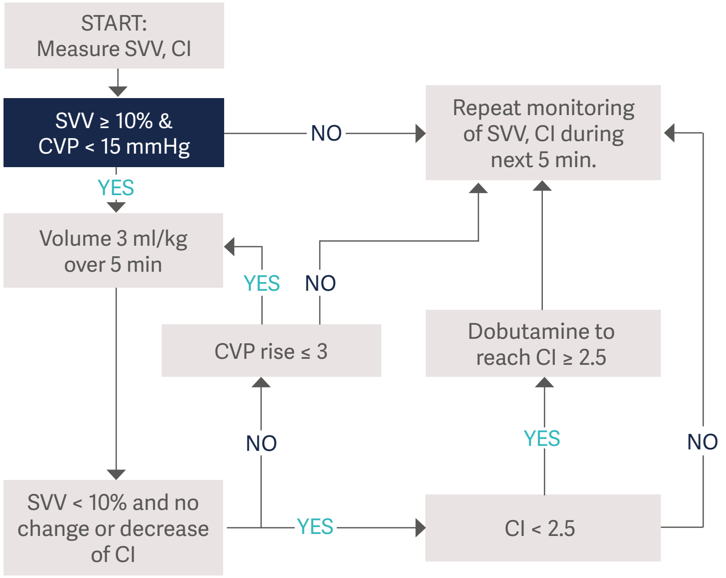
Based on (8), (9), (10) und NICE Guideline Algorithm

Discipline	Abdominal, orthopaedic, gynaecological & urological surgery
Publication	Kuper et al. 2011
Type of study	Comparison (before versus after) during a technology adoption project at three different hospital sites.
n	658 (control group) / 649 (study group)
Inclusion criteria	ASA > 1
Centers	Royal Derby Hospital (UK), Whittington Hospital (London, UK), Manchester Royal Infirmary (UK)
Parameters	SV
Outcome	LoS ↓ 3.6 days (25%)

- (+) Easy and simple

- (−) No fluid responsiveness assessment before fluid administration
- (−) No perfusion pressure parameters
- (−) Does not take into account that some patients may need vasopressors / inotropes to increase SV and CI
- (−) No oxygen balance parameters

Benes Algorithm



Based on (11)

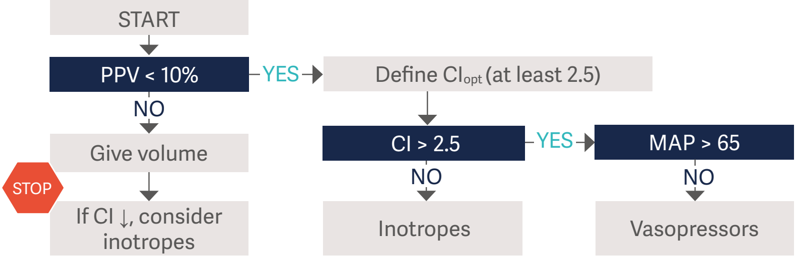
Discipline	Abdominal surgery
Publication	Benes et al. 2010
Type of study	Randomised controlled trial
n	60 (control group) / 60 (study group)
Indications	Major abdominal surgery
Inclusion criteria	Anticipated OR time > 120 min or blood loss > 1,000 mls
Location	Charles University Plzen (CZ)
Parameters	SVV, CVP, CI
Outcome	Patients with complications ↓ 28.3%, No of complications ↓ 56% LoSHospital ↓ 10%

- ⊕ Includes fluid responsiveness
- ⊕ Considers use of inotrope

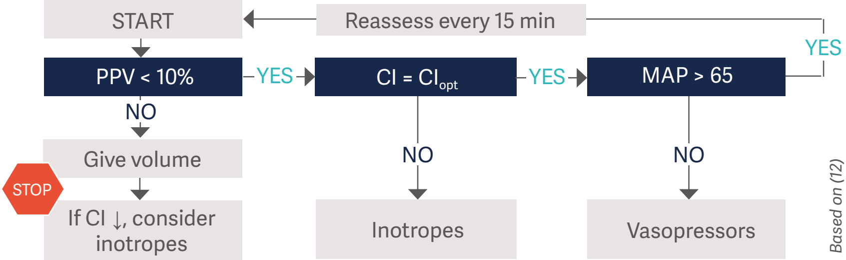
- ⊖ No oxygen balance parameters
- ⊖ CVP is a poor preload parameter
- ⊖ No perfusion pressure parameters

Salzwedel Algorithm

A) Define a reference CO during the initial phase



B) Use CI_{opt} for further intraoperative optimisation



Based on (12)

Discipline	Abdominal surgery
Publication	Salzwedel et al. 2013
Type of study	Multi-center randomised controlled trial
n	79 (control group) / 81 (study group)
Indications	Major abdominal surgery
Inclusion criteria	Anticipated OR time > 120 min or blood loss > 20%, ASA 2 or 3, CVC, arterial line
Locations	Arkhangelsk (RU), Hamburg-Eppendorf (DE), Kiel (DE), Szeged (HU), Valencia (ES)
Parameters	PPV, CI, MAP
Outcome	Patients with complications ↓ 41.7% , No of complications ↓ 27.7%

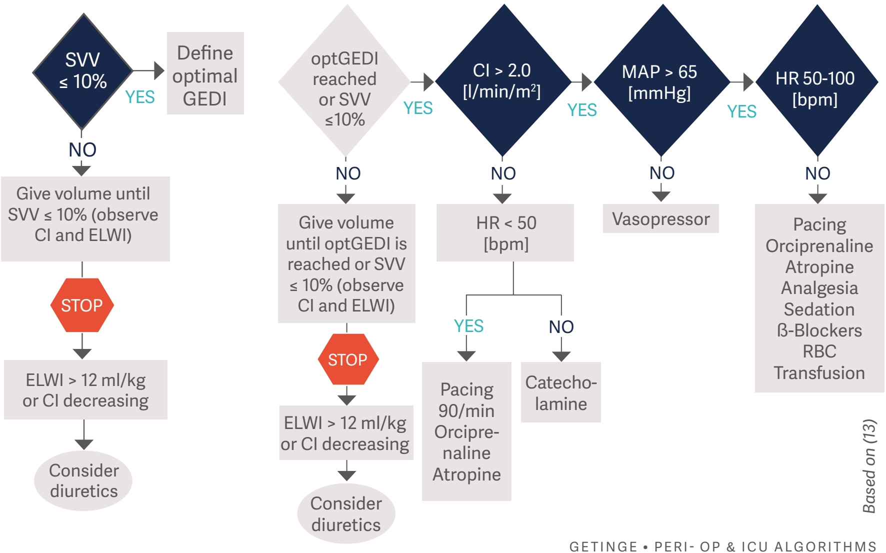
- ⊕ Individualised per patient
- ⊕ Includes fluid responsiveness
- ⊕ Considers use of inotropes / vasopressors
- ⊕ Includes perfusion pressure
- ⊕ Easy and simple

- ⊖ No oxygen balance parameters

Goepfert Algorithm

A) Define optGEDI during the initial phase

B) Use optGEDI for further intraoperative optimisation & ICU stay



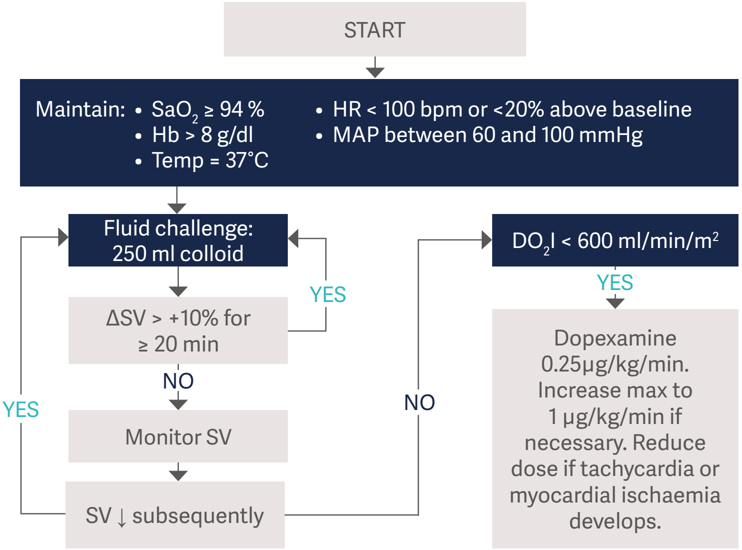
Based on (13)

Discipline	Abdominal surgery
Publication	Goepfert et al. 2013
Type of study	Prospective randomised controlled trial
n	50 (control group) / 50 (study group)
Indications	Coronary Artery Bypass Grafting (CABG), Aortic Valve Replacement (AVR), CABG + AVR
Inclusion criteria	Anticipated OP time > 120 min or blood loss > 20%, ASA 2 or 3, CVC, arterial line
Location	University Hospital Hamburg-Eppendorf (DE)
Parameters	SVV, GEDI, ELWI, CI, MAP
Outcome	No of complications ↓ 36 %, LoS_{ICU} ↓ 32 %

- ⊕ Individualised per patient
- ⊕ Includes fluid responsiveness
- ⊕ Includes perfusion pressure
- ⊕ Considers use of inotropes / vasopressors

- ⊖ No oxygen balance parameters
- ⊖ Complex algorithm

Pearse Algorithm



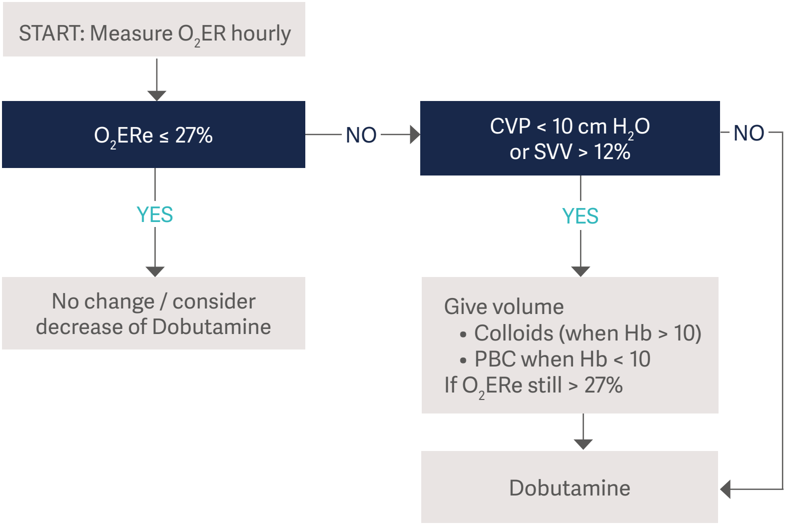
Based on (14)

Discipline	High-risk general surgery
Publication	Pearse et al. 2005
Type of study	Randomised controlled trial with concealed allocation
n	60 (control group) / 62 (study group)
Indications	General major surgery
Inclusion criteria	High risk of post-op complications ASA ≥ 3
Center	St George's Hospital London (UK)
Parameters	SV, DO_2I
Outcome	Patients with complications ↓ 34 %, LoSHospital ↓ 21 %

- ⊕ Includes fluid responsiveness
- ⊕ Considers use of inotropes

- ⊖ No oxygen balance parameters
- ⊖ Not individualised: DO_2I ≥ 600 can not be reached in every patient
- ⊖ Complex algorithm

Donati Algorithm



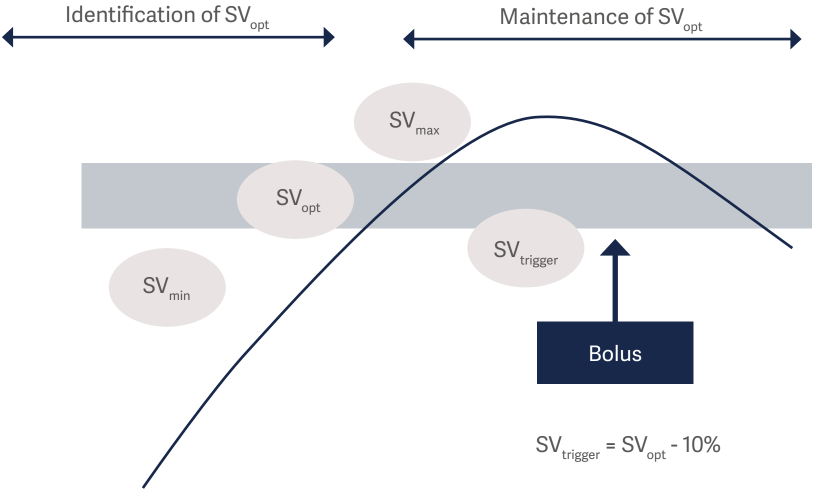
Based on (15)
O_2ER estimate (O_2ERe) = ((SaO_2-$ScvO_2$)/SaO_2), PBC - Packed Red Blood Cells

Discipline	Abdominal surgery
Publication	Donati et al. 2007
Type of study	Multi-center randomised controlled trial
n	67 (control group) / 68 (study group)
Indications	Elective abdominal extensive surgery, abdominal aortic surgery
Inclusion criteria	ASA ≥ 2
Locations	Italian hospital sites: Ancona, Fano, Perugia, Varese, Verona, Pesaro, Genova, Jesi, Senigallia
Parameters	O_2ERe, CVP, SVV
Outcome	No of complications ↓ 60 %, LoS ↓ 16 %

- ⊕ Includes oxygen delivery parameter
- ⊕ Includes oxygen balance parameter
- ⊕ Considers use of inotropes

- ⊖ $ScvO_2$ cannot be used in all indications instead of SvO_2 for accurate O_2ER calculation
- ⊖ CVP is a poor preload parameter

GDFT during hip revision



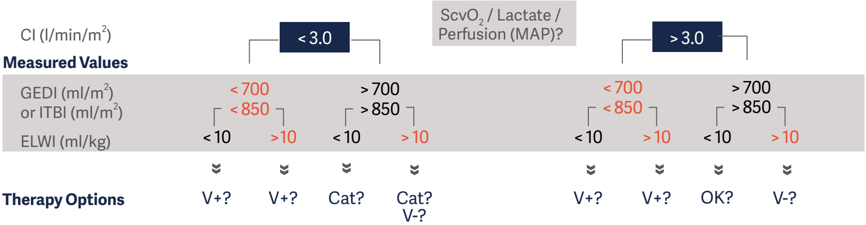
Based on (16)

Discipline	Orthopaedic surgery
Publication	Habicher et al. (2016)
Type of study	Interventional
n	130 (study group), 130 (control group)
Indications	Arthroplasty
Inclusion criteria	patients undergoing redo hip surgery
Locations	Charite University, Berlin, Germany
Parameters	SV
Outcome	Reduced postsurgical complications and reduction in postoperative bleeding significant lower morbitity rate (p=0.006), shorter median hospital length of stay (p=0.003)

⊕ Simple protocol

⊖ Contraindications for inotropics (> 2 items)
- Coronary heart disease
- Angina pectoris
- Diabetes mellitius
- Renal dysfunction
- Stroke

Getinge ICU algorithm



Targeted Values

• GEDI (ml/m²) (if ELWI >10 → 700-800)	> 700
• GEF (%)	> 25
• CFI (1/min)	> 5
• ELWI (ml/kg) (slow response)	≤ 10

- Volume Responsiveness? (Passive Leg Raising / Endexpiratory Occlusion Test / Volume Challenge / SVV / PPV?)

- Contractility Problem? (GEF / CFI / Echo?)

V+ = volume loading V- = volume withdrawal Cat = catecholamine / cardiovascular agents
Please reevaluate your clinical decisions and the set target parameters.

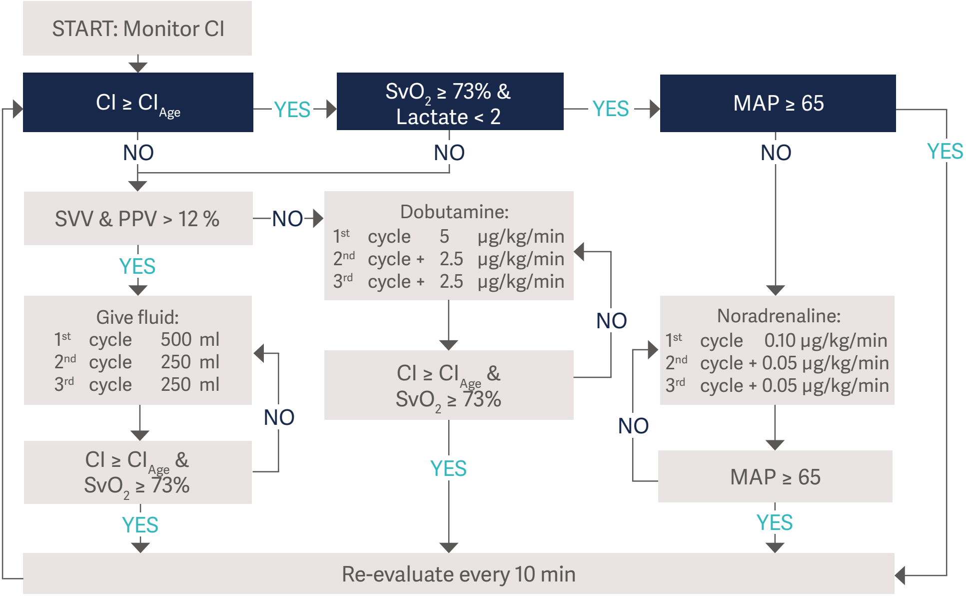
Additionally the following should be considered :

Is cardiac output adequate ?	• Check also $ScvO_2$, Lacate, ΔPCO_2v-a and clinical signs of hypoperfusion
Is the patient volume responsive?	• Check SVV or PPV if applicable, if not consider passive leg raising, end-expiratory occlusion test or volume challenge
Are there warning parameters for volume overload?	• Check if ELWI increases after volume administration • Check for clinical signs of volume overload
Is cardiac contractility impaired?	• Check CFI or GEF • Consider Echocardiography?

- ⊕ Considers use of inotropes/ vasopressors
- ⊕ Includes volumetric preload
- ⊕ Includes lung water

- ⊖ No parameters for perfusion pressure
- ⊖ No parameters for oxygen balance
- ⊖ Not individualised

Oldenburg algorithm



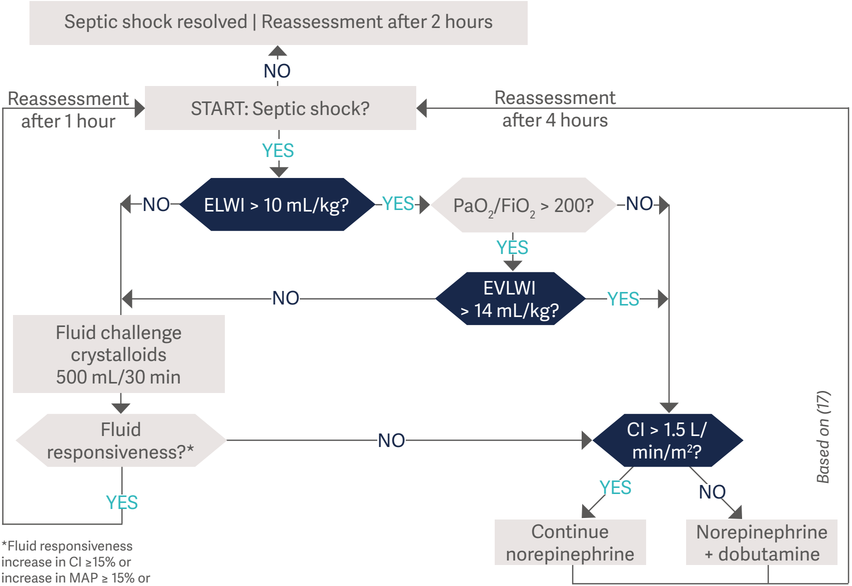
$$CI_{Age<45} = 3.5,\ CI_{Age<75} = 3.0,\ CI_{Age>75} = 2.5\ l/min/m^2$$

Developed by Andreas Weyland, Klinikum Oldenburg, Germany

- ⊕ Includes fluid responsiveness
- ⊕ Considers use of inotropes
- ⊕ Includes oxygen balance parameters
- ⊕ Includes perfusion pressure

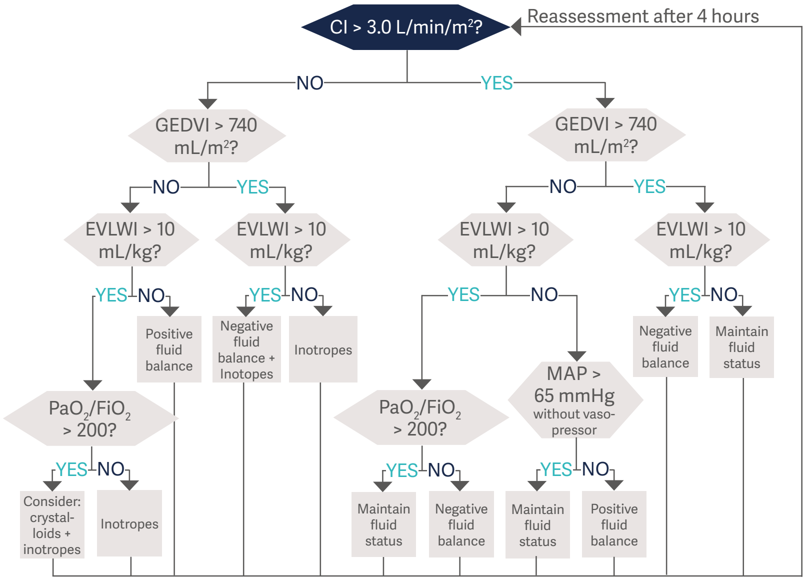
- ⊖ Complex algorithm

Septic Shock Management Algorithm (<24 h)



*Fluid responsiveness
increase in CI ≥15% or
increase in MAP ≥ 15% or
increase in CI + increase in MAP ≥ 20%

Septic Shock Management Algorithm (>24 h)



Discipline	Anesthesiology and Intensive Care Medicine
Publication	Saugel et al.
Type of study	Review Article
Indications	Septic Shock
Parameters	CI, MAP, GEDI, ELWI
Outcome	suggestion for treatment algorithm

- (+) Provides guidance for the initial hours of septic shock
- (+) Transpulmonary thermodilution adds additional valuable information
- (−) Not yet tested in a randomized controlled trial

Literature

1. Shoemaker WC et al., Prospective trial of supranormal values of survivors as therapeutic goals in high-risk surgical patients.Chest 1988; 94(6): 1176-86.
2. Monnet X & Teboul JL, Assessment of volume responsiveness during mechanical ventilation: recent advances. Crit Care 2013; 17(2): 217.
3. Monnet X et al., Passive leg raising predicts fluid responsiveness in the critically ill*. Crit Care Med 2006; 34(5): 1402-7.
4. Cavallaro F et al., Diagnostic accuracy of passive leg raising for prediction of fluid responsiveness in adults: systematic review and meta-analysis of clinical studies. Intensive Care Med 2010; 36(9):1475-83.
5. Monnet X et al., Predicting volume responsiveness by using the end-expiratory occlusion in mechanically ventilated intensive care unit patients. Crit Care Me 2009; 37(3):951-6.
6. Myatra et al..,Use of ‚tidal volume challenge' to improve the realiability of pulse pressure variation. Crit Care 2017; 21(1):60
7. Biais et al., Changes in Stroke Volume Induced by Lung Recruitment Maneuver Predict Fluid Responsiveness in Mechanically Ventilated Patient in the Operating Room, Anesthesiology. 2017;126(2):260-267
8. National Institute for health and Clinical Excellence, CardioQ-ODM oesophageal doppler monitor. NHS 2011.
9. Kuper M et al., Intraoperative fluid management guided by oesophageal Doppler monitoring. Bmj 2011; 342: d3016.
10. Vallet B et al., Strategie du remplissage vasculaire perioperatoire / Guidelines for perioperative haemodynamic optimization. Societe Francais d'Anesthesie et de Reanimation. Afar 2013; 32(6): 454-462.
11. Benes J et al., Intraoperative Fluid Optimization using stroke volume variation in high risk surgical patients: results of prospective randomized study. Crit Care 2010; 14(3):R118.
12. Salzwedel C et al., Perioperative goal-directed hemodynamic therapy based on radial arterial pulse pressure variation and continuous cardiac index trending reduces postoperative complications after major abdominal surgery: a multi-center, prospective, randomized study. Crit Care 2013; 17:R191.
13. Goepfert M et al., Individually Optimised Haemodynamic Therapy Reduces Complications and Length of Stay in the Intensive Care Unit - A Prospective, Randomised Controlled Trial. Anesthesiology 2013; 119(4): 824-836.
14. Pearse R et al., Early goal-directed therapy after major surgery reduces complications and duration of hospital stay. A randomised, controlled trial. Crit Care 2005; 9(6): R687-93.
15. Donati A et al., Goal-directed intraoperative therapy reduces morbidity and length of hospital stay in high risk surgical patients. Chest 2007; 132: 1817-1824.
16. Habicher M. et. Al., Implementation of goal-directed fluid therapy during hip revision arthroplasty: a matched cohort study; Perioper Med (Lond). 2016 Dec 13;5:31
17. Saugel et.al.; Advanced Hemodynamic Management in Patients with Septic Shock, Biomed Res Int. 2016;2016

Notes

Notes

Appendix

Notes

Hemodynamic – Normal Values

Group	Category	Parameter	Abbreviation	Normal value
		Central Venous Oxygenation - Oxygenation Balance (Oxygen load of the venous blood after passing through the organs)	$ScvO_2$ **	70-80 %
		O_2 Consumption (Consumption of O_2 by organs)	VO_2I	125-175 ml/min/m²
Oxygen Delivery		O_2 Delivery (Delivery of O_2 via blood to organs)	DO_2I	400-650 ml/min/m²
Oxygen Delivery		Haemoglobin (Oxygen transporter in blood)	Hb ***	8.7-11.2 mmol/l (Male) 7.5-9.9 mmol/l (Female)
Oxygen Delivery		Arterial / capillary oxygen saturation (Oxygen load of arterial blood)	SaO_2 / SpO_2	96-100 %
Blood Flow	Flow	Cardiac Index	CI	3-5 l/min/m²
Blood Flow	Flow	Pulse Contour Cardiac Index (Cardiac Index related to body surface)	PCCI	3-5 l/min/m²
Blood Flow	Chronotropy	Heart Rate	HR	60-80 bpm
Stroke Volume		Stroke Volume Index (Output per heart beat)	SVI	40-60 ml/m²
Stroke Volume	Preload	Global Enddiastolic Volume Index (Volume of blood in the heart)	GEDI	680-800 ml/m²
Stroke Volume	Preload	Intrathoracic Blood Volume Index (Volume of blood in heart and lungs)	ITBI	850-1000 ml/m²
Stroke Volume	Preload	Stroke Volume Variation (Dynamic fluid responsiveness)	SVV *	0-10 %
Stroke Volume	Preload	Pulse Pressure Variation (Dynamic fluid responsiveness)	PPV *	0-13 %
Stroke Volume	Afterload	Systemic Vascular Resistance Index (Resistance of vascular system)	SVRI	1700-2400 dyn*sec*cm⁻⁵*m²
Stroke Volume	Afterload	Mean Arterial Pressure	MAP	70-90 mmHg
Stroke Volume	Contractility	Global Ejection Fraction (Ratio of stroke volume and preload)	GEF	25-35%
Stroke Volume	Contractility	Left Ventricular Contractility (Increase of arterial pressure over time)	dPmax	Trend information
Stroke Volume	Contractility	Cardiac Function Index (Ratio of CI and preload)	CFI	4.5-6.5 1/min
Stroke Volume	Contractility	Cardiac Power Index (Global cardiac performance)	CPI	0.5-0.7 W/m²
	Lung	Extravascular Lung Water Index (Lung oedema)	ELWI	3-7 ml/kg
	Lung	Pulmonary Vascular Permeability Index (Permeability of lung tissue)	PVPI	1.0-3.0
	Liver	Plasma Disappearance Rate ICG (Performance of the liver)	PDR	18-25 %/min
	Liver	Retention rate of ICG after 15 minutes (Performance of the liver)	R15	0-10 %

Absolute values (non-indexed values) are only usable in trend screens and have no normal range. * SVV and PPV are only applicable in fully ventilated patients without cardiac arrhythmias. ** A high-normal / high $ScvO_2$ can be a sign of insufficient O_2 utilisation *** 14-18 g/dl (Male); 12-16 g/dl (Female)

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Getinge is a global provider of innovative solutions for operating rooms, intensive care units, sterilization departments and for life science companies and institutions. Based on our firsthand experience and close partnerships with clinical experts, healthcare professionals and medtech specialists, we are improving the everyday life for people - today and tomorrow.

This document is intended to provide information to an international audience outside of the US.

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