Noninvasive Hemodynamic Monitoring In The Setting of Hypoperfusion and Appropriate Perioperative Fluid Management

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Objective(s)

- To evaluate and appraise the integration of Noninvasive Hemodynamic Monitoring (NHDM) into perioperative fluid management strategies, aiming to enhance patient outcomes.

Background

- Traditional fluid management uses a uniform 4-2-1 rule for all patients.
- Modern approaches recommend personalized care, **as fluid needs vary by individual.** NHDM personalizes fluid management to optimize outcomes and prevent complications.
- Intraoperative hypotension is linked to adverse outcomes such as renal insufficiency and increased mortality.
- This technology matches the accuracy of invasive methods and allows timely fluid adjustments.

"Historic" 4-2-1 Rule Administration

It operates on a tiered system: for the first 10 kg of body weight the rate is 2 mL/kg/hour, then the rate is increased by 4 mL/kg/hour for the next 10 kg (from 10 to 20 kg), and for any weight above 20 kg there is an addition of 1 mL/kg/hour to the hourly rate.[7]

Maintenance: 4:2:1 rule
Deficits: Maintenance x hr(s) fasting
3rd space losses: 10-15 ml/kg/hr
Blood loss: 3:1 replacement with crystalloid, 1:1 replacement with colloids

The Holliday – Segar 4-2-1 Rule

to estimate Maintenance Hourly Fluid (WATER) Requirements

Weight (kg)	Hourly	Daily
<10 kg	4 mL/kg/hr.	100 mL/kg/day
10 –20 kg	40 mL + 2 mL/kg for every kg >10 kg	1000 mL + 50 mL/kg/day for every kg >10
>20 kg	60 mL + 1 mL/kg for every kg >20 kg	1500 mL + 20 mL/kg/day for every kg > 20

4-2-1 rule EXAMPLES

For a 5 kg infant, Maintenance Hourly Fluid (water) Requirements would be:

4 x 5 = 20ml/hr.

Daily rate: 20 x (24hr) = 480 ml/day

For a 15 kg child, Maintenance Hourly Fluid (water) Requirements would be:

4 x 10 = 40 ml + 2 x 5 = 10 ml
Total: 40 + 10 = 50ml/hr.

Daily rate: 50 x (24hr) = 1200 ml/day

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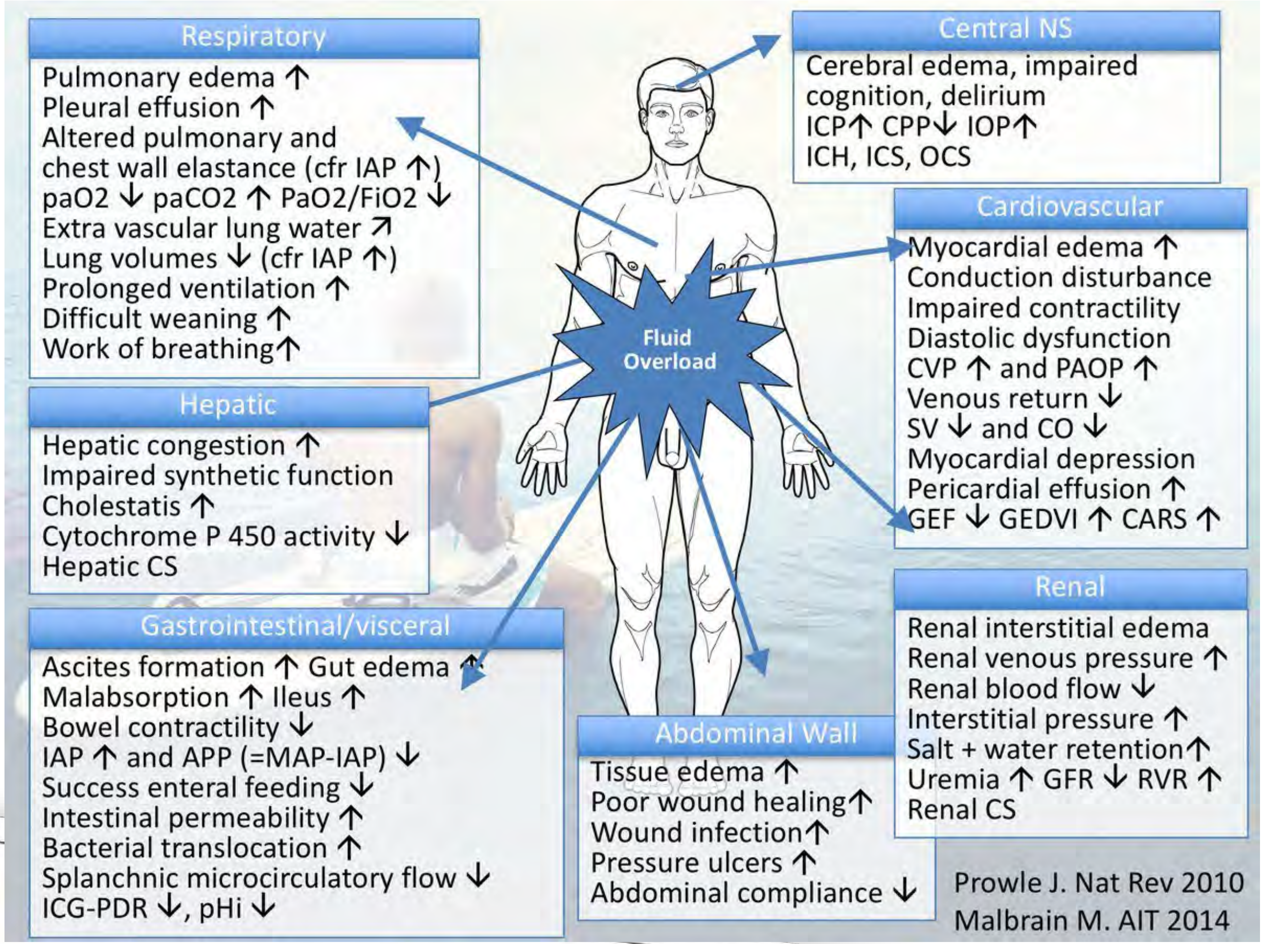
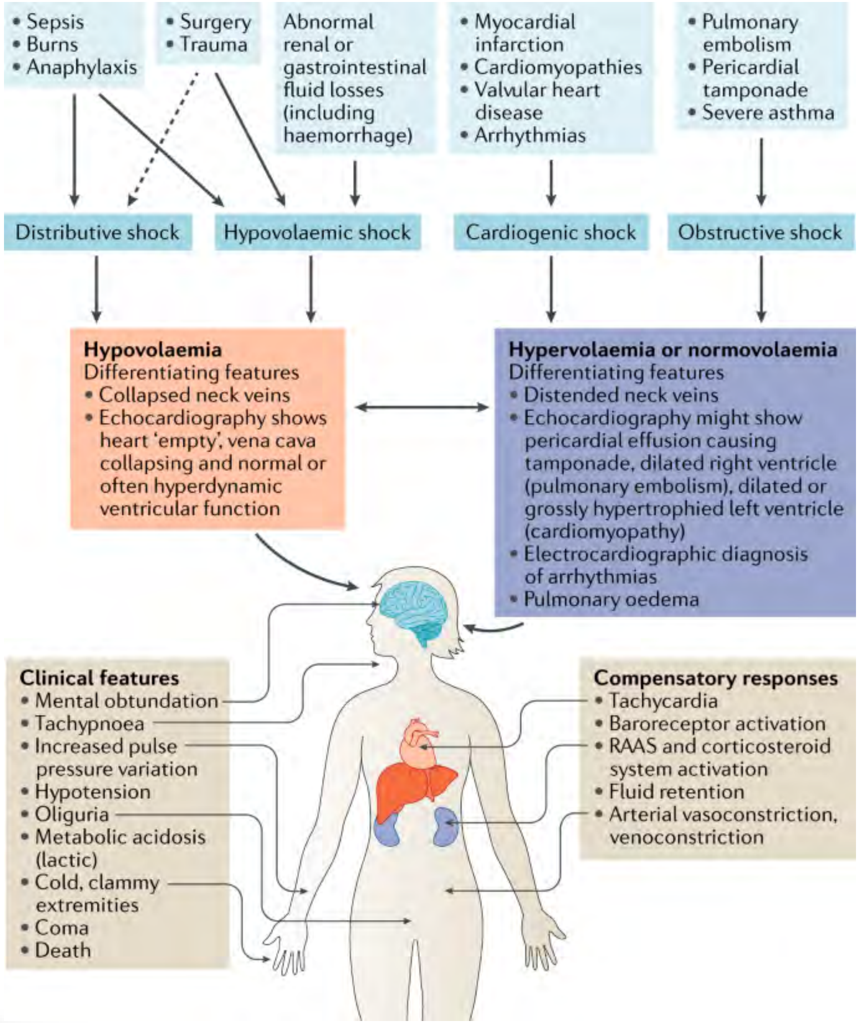
Negative Impacts of Excess Fluid



Source: Prowle JR, Kirwan CJ, Bellomo R. Fluid management for the prevention and attenuation of acute kidney injury. *Nat Rev Nephrol*. 2014;10(1):37-47. doi:10.1038/nrneph.2013.232

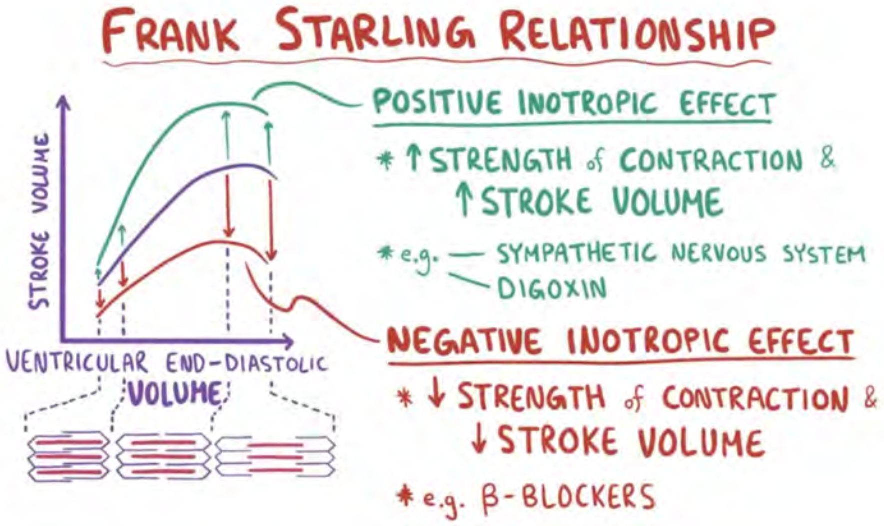
Hazards of inadequate fluid administration/under resuscitation

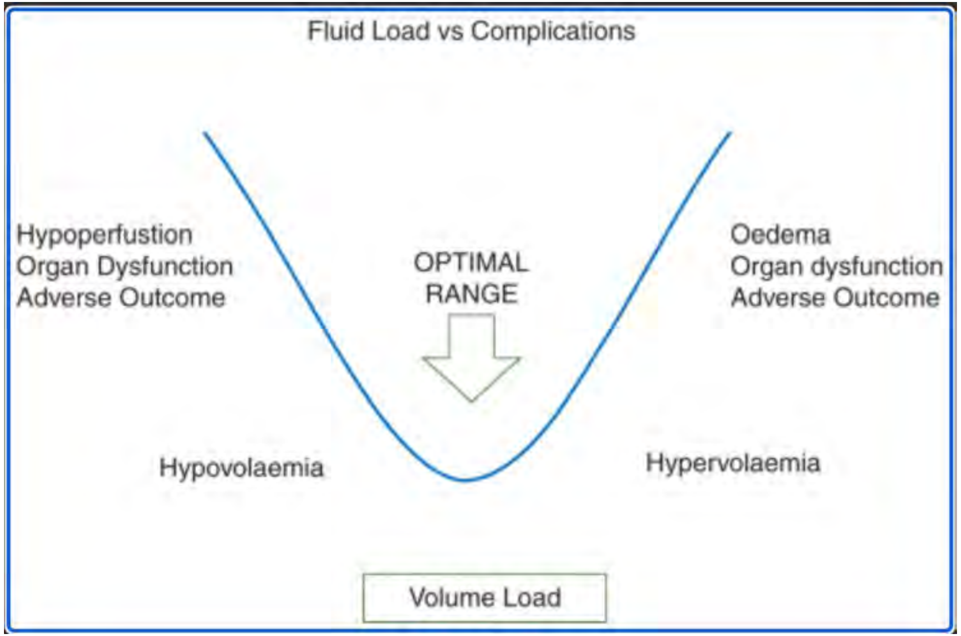
- **Global Tissue Hypoperfusion**: leading to systemic issues affecting multiple organs due to insufficient blood flow[1].
- **Urinary Output and Acute Kidney Injury (AKI)**: An intraoperative urinary output of < 0.3 mL/kg per hour significantly ↑ risk of AKI, with an odds ratio (OR) of 2.65, indicating a more than two-fold increased risk[1,3].
- **GI Complications**: Inadequate blood flow to the intestines → gut ischemia, potentially escalating to sepsis if not addressed promptly[1].
- **Cardiac Complications**: Insufficient blood flow to the heart can precipitate myocardial ischemia, which may lead to an infarction and, in severe cases, result in death.



Maintaining Fluid balance for Effective Circulation/Hemodynamic

- To preserve oxygen delivery to the tissues
- To maintain electrolyte and physiological homeostasis
- **On an individual basis**





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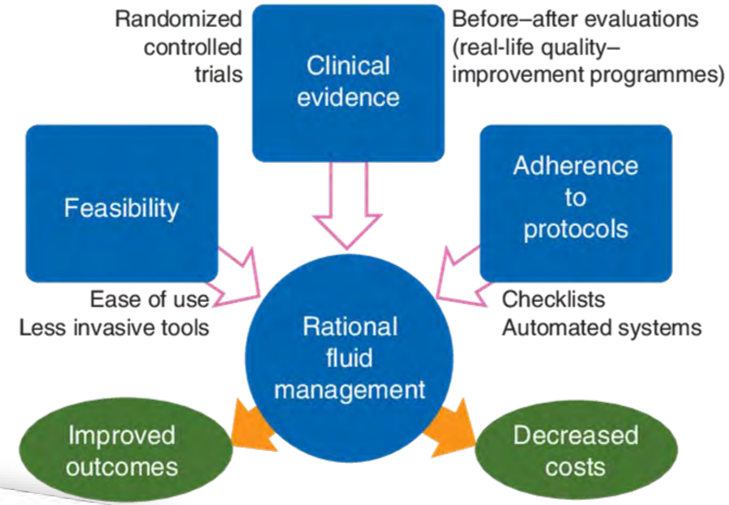
Current Trends in Fluid Management

Advanced Monitoring Technologies: Transition from invasive to sophisticated noninvasive technologies for safer, real-time monitoring of hemodynamics → improving decision-making during anesthesia.

Goal-Directed Fluid Therapy (GDFT): Utilization of dynamic measurements like stroke volume variation (SVV) and pulse pressure variation (PPV) → tailor fluid administration more accurately.

Integration of Dynamic Measurements: Shift from static to dynamic variables for assessing fluid responsiveness.

Minimally Invasive Techniques: Emphasis on reducing complications with the adoption of less invasive methods.



Appropriate Goal Directed Fluid Therapy (GDFT) with NHDM

GDFT is increasingly recognized for its benefits in perioperative settings, particularly as part of Enhanced Recovery After Surgery (ERAS) protocols → aims to optimize fluid balance, using dynamic measurements (i.e. SVV and PPV) to assess fluid responsiveness.

Continuous dynamic process → physiologic end points (based on hemodynamics, rather than an prehistoric rul)

Administration of fluid challenge of crystalloid/colloid, assess affect in SV/PVV/MAP/UO (through NHDM integration)

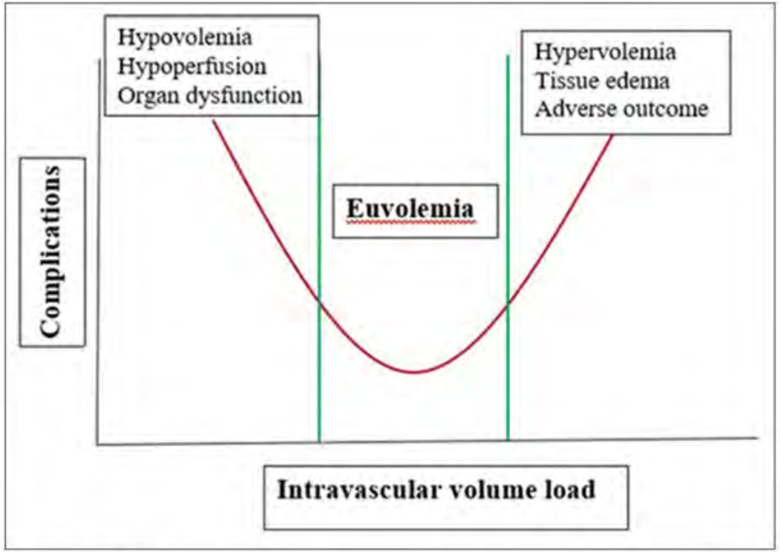


Figure 1: A depiction of how fluid overload can lead to interstitial edema and local inflammation, impairing the regeneration of collagen, and thus negatively affecting tissue healing and increasing the risk of wound dehiscence, wound infections, and anastomotic leakage

Indicators of Adequate Fluid Volume Resuscitation and Hemodynamic Parameters

Mean Arterial Pressure (MAP) > 65 mm Hg

- Shown to improve mortality and adequate end organ perfusion, rough guideline due to compensatory vasoconstriction (hypoperfusion)

Urine output between 0.5 to 1.0/1.5 ml/kg/hr

- <0.3 ml/kg/hr → ↑ risk of Acute Renal Failure (ARF) (↓ end organ perfusion)

~~**Central Venous Pressure (CVP) > 5 mm Hg***~~

- NO LONGER a reliable indicator of adequate fluid resuscitation

Lactate levels ↓ trends decreasing

- An ↑ indicates a decrease in tissue perfusion

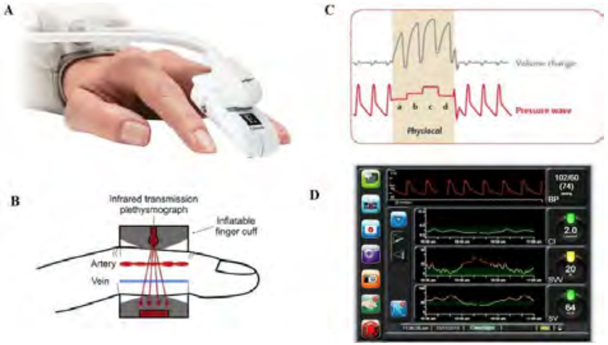
Non-invasive Blood Pressure (NIBP) within 15 to 20% baseline

- Trend MAPs and Systolic BPs (SBPs)

Key Literature Review Results for NHDM

- ★ **Perioperative hemodynamic optimization** reduces complications and improves survival rates, reducing morbidity and mortality.
- ★ **Effective hemodynamic control** is best achieved using a goal-directed algorithm.
- ★ **Monitoring techniques** include evaluating blood pressure, cardiac output, intravascular volume, autoregulation, and tissue oximetry.
- ★ **Advancements in technology** have reduced the necessity for invasive monitoring, favoring minimally invasive and noninvasive methods.
- ★ **Economic benefits** are noted with the implementation of goal-directed hemodynamic strategies.

Table 1: Overview of monitoring parameters of different hemodynamic monitors. Maik et al. (2014)



Overview of the monitoring parameters of different hemodynamic monitors.

	Hemodynamic monitors							
	Continuous blood pressure	Stroke volume	Cardiac output	Contractility	Systemic vascular resistance	Stroke volume variation	Pulse pressure variation	Other parameters
	Noninvasive							
	Ultrasound							
TTE	−	+	+	+	−	+	−	
Suprasternal Doppler (USCOM®)	−	+	+	+	+	+	−	Cardiac Power
	Bioimpedance and bioreactance							
Bioimpedance (BioZ®)	−	+	+	+	+	−	−	TFC LCWI
Bioreactance (Cheetah NICOM®)	−	+	+	+	+	+	−	TFC DO_2I
	Volume clamp method							
Clearsight®	+	+	+	−	+	+	−	
CNAP®	+	+	+	−	+	+	+	
Finapres®	+	+	+	+	+	−	−	
	Radial artery applanation technique							
Tensys®	+	−	−	−	−	−	−	
	Photoplethysmography							
Masimo Radical 7®	−	−	−	−	−	−	−	PVI
	Minimally invasive							
	Ultrasound							
TEE	−	+	+	+	−	+	−	
Esophageal Doppler (CardioQ®)	−	+	+	+	+	+	−	FTc
	Uncalibrated arterial waveform analysis							
ProAQt®	+	+	+	+	+	+	−	
LIDCO rapid®	+	+	+	+	+	+	+	
Flotrac®	+	+	+	+	+	+	−	
	Invasive							
PAC (CCOmbo PAC®)	−	+	+	+	+	−	−	SvO_2
PICCO®	+	+	+	+	+	+	−	$ScvO_2$ GEDV ITBI GEF EVLW
LIDCO plus®	+	+	+	+	+	+	+	$ScvO_2$ ITBV
Volumeview®	+	+	+	+	+	+	−	EVLW GEDV GEF

+: Yes, -: No, TTE-Trans-thoracic echocardiography, TEE- Trans-esophageal echocardiography, TFC-Thoracic Fluid Content, LCWI-Left Cardiac Work Index, DO_2I-Oxygen Delivery, PVI-Pleth Variability Index, FTc-Flow Time corrected, SvO_2-mixed venous saturation, $ScvO_2$-central mixed venous saturation, GEDV-Global End-Diastolic Volume, ITBI-Intrathoracic Blood Index, GEF-Global Ejection Fraction, EVLW-Extravascular Lung Water, ITBV, IntraThoracic Blood Volume.

B.I. Naik, M.E. Durieux / Best Practice & Research Clinical Anaesthesiology 28 (2014) 477–488

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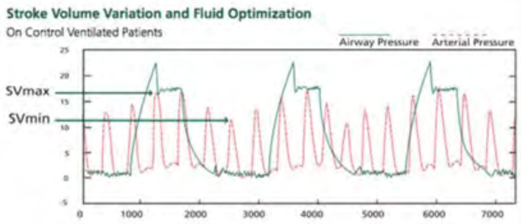
FloTrac®/Vigileo

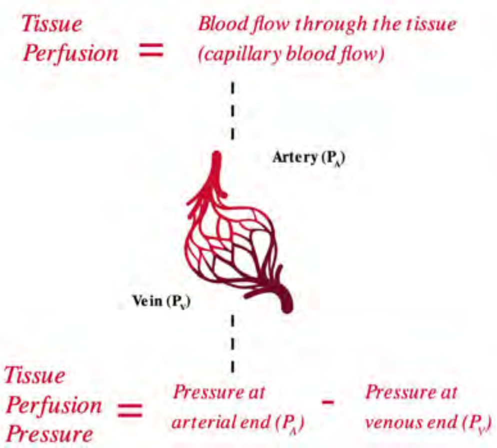
Waveform analysis to calculate stroke volume and cardiac output

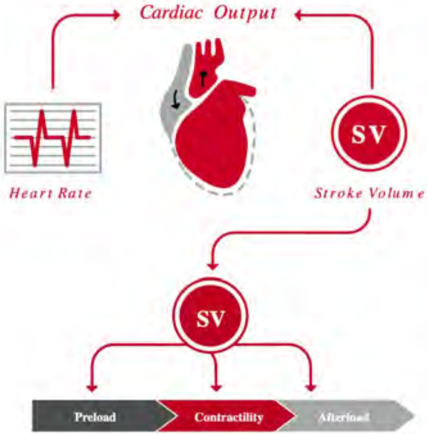
Requires mechanical ventilation TV 8 ml/kg

Affected by PEEP

- Algorithm is based on the principle that aortic pulse pressure (PP) ∝ stroke volume (SV) and inversely ∝/b r/t aortic compliance.
- Adjusts for compliance based on age, gender, and body surface area (BSA).
- Continuously detects and analyzes beats, allowing the use of SVV to guide volume resuscitation, even in patients with frequent premature atrial or ventricular contractions and most arrhythmias.







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Clearsight®

Technology is based on 2 methods: volume clamp method to continuously measure BP and physiological method for calibration

Volume Clamp Method

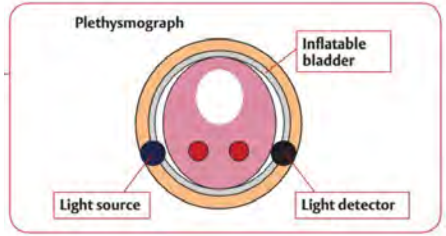
- Equalizes pressure on artery wall by clamping to constant volume.
- Adjusts cuff pressure 1000x/sec.

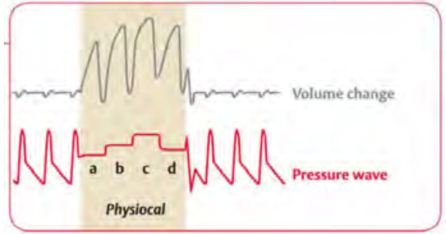
Physiocal Method

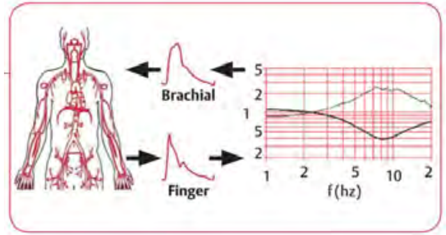
- Determines arterial ‘unloaded’ volume (no pressure gradient).
- Periodic adjustments for muscle tone changes.
- Calibration: starts at 10 beats, increases to 70 beats when stable; reliable >30 beats.

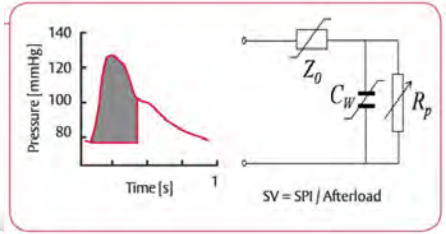
Cardiac Output Calculation

- Stroke volume = SPI + physiological model.
- Adjusts for age, gender, height, weight.
- Cardiac output = stroke volume × heart rate, updates every beat.

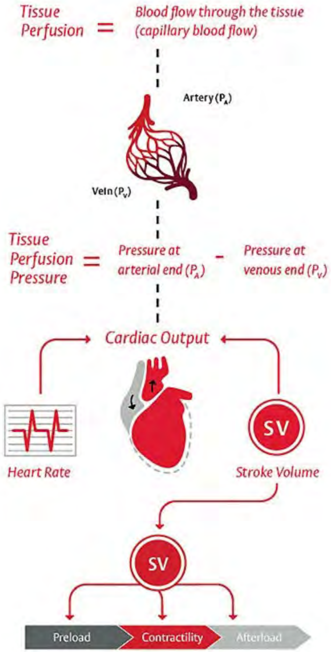








Cockpit screen on HemoSphere advanced monitor



Limitations to NHDM technology

Accuracy Concerns: Some devices may not be as precise as invasive methods, especially in challenging conditions like patient movement or arrhythmias.	**Validation Gaps**: Not all devices are tested across diverse clinical settings or populations.
Technological Constraints: Limitations in sensor accuracy and data processing can hinder the monitoring of rapid physiological changes.	**Cost and Complexity**: NHDM devices can be costly and require specific training, limiting their use in resource-scarce settings.
Patient Variability: Factors like obesity or vascular disease can reduce the effectiveness of NHDM.	

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Other Considerations with Fluid Management Planning

Pre-Surgery:
- Clear fluids up to 2 hrs pre-anesthesia
- ≥45g carbs in fluids (except type I diabetics)
- Avoid IV fluids if clear fluids taken + iso-osmotic bowel prep
- No hyper-/hypo-osmotic bowel prep

During and Post-Surgery:
- Hemodynamic framework + GDFT
- Choose NHDM monitoring equipment based on case
- Don't treat intraoperative oliguria w/ fluids → investigate
- Address anuria/hypoperfusion immediately
- Tailor fluid management to clinical needs
- Use vasoconstrictors for hypovolemia if needed
- Buffered isotonic crystalloids for colorectal surgery
- Unrestricted oral fluids post-surgery if tolerated

Summary

- NHDM = real-time hemodynamic data → shift from invasive to non-invasive methods
- GDFT approach that adapts to individual patient needs → preventing iatrogenic hypovolemia/overload
- Limitations ≠ variability, integration, cost, and training
- Consensus Recommendations:
  - Preop: Clear fluids >2 hrs before surgery, w/ carbohydrates to boost insulin sensitivity
  - Intraop Use NHDM to guide fluid therapy, adjust for changes.
  - Postop: Continue monitoring and GDFT, especially for high risk patients.
- Benefits = ↑ fluid management, ↓ post op sequelae, and ↑ recovery

Is the Future of Non-Invasive Hemodynamic Monitoring Here and Ready for Primetime?

References

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Scan for references!

Scan for eval!

Thank you!

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