OSYPKA MEDICAL

A WINDOW INTO PRECISION HEMODYNAMICS

Optimizing clinical analysis in pediatric patients



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What will we cover?

1. **Electrical velocimetry in pediatrics**
2. **Its clinical usefulness**
3. **Published evidence**
4. **Clinical experience in Chile**
5. **Future challenges in its use**



“Small patients, big challenges”



“The Doctor”; Sir Samuel Luke Fildes; 1887

Given the blood pressure we see, is flow adequate?

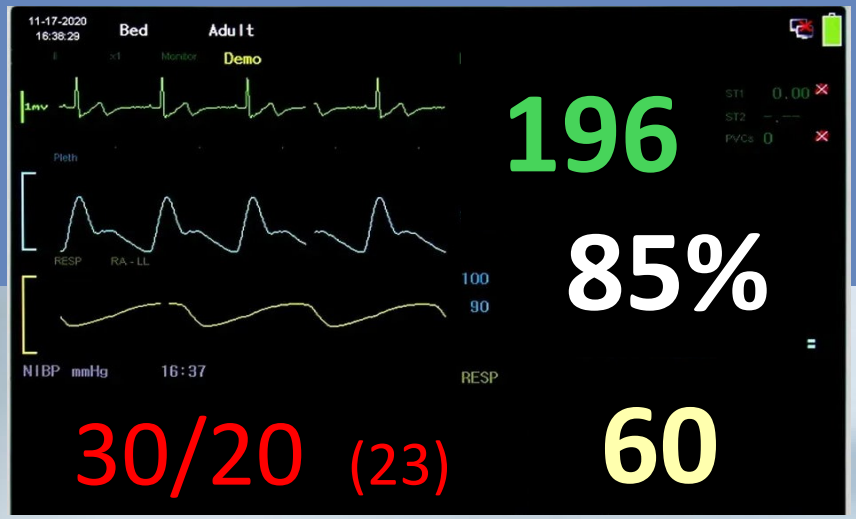
Will the patient respond to fluid expansion?

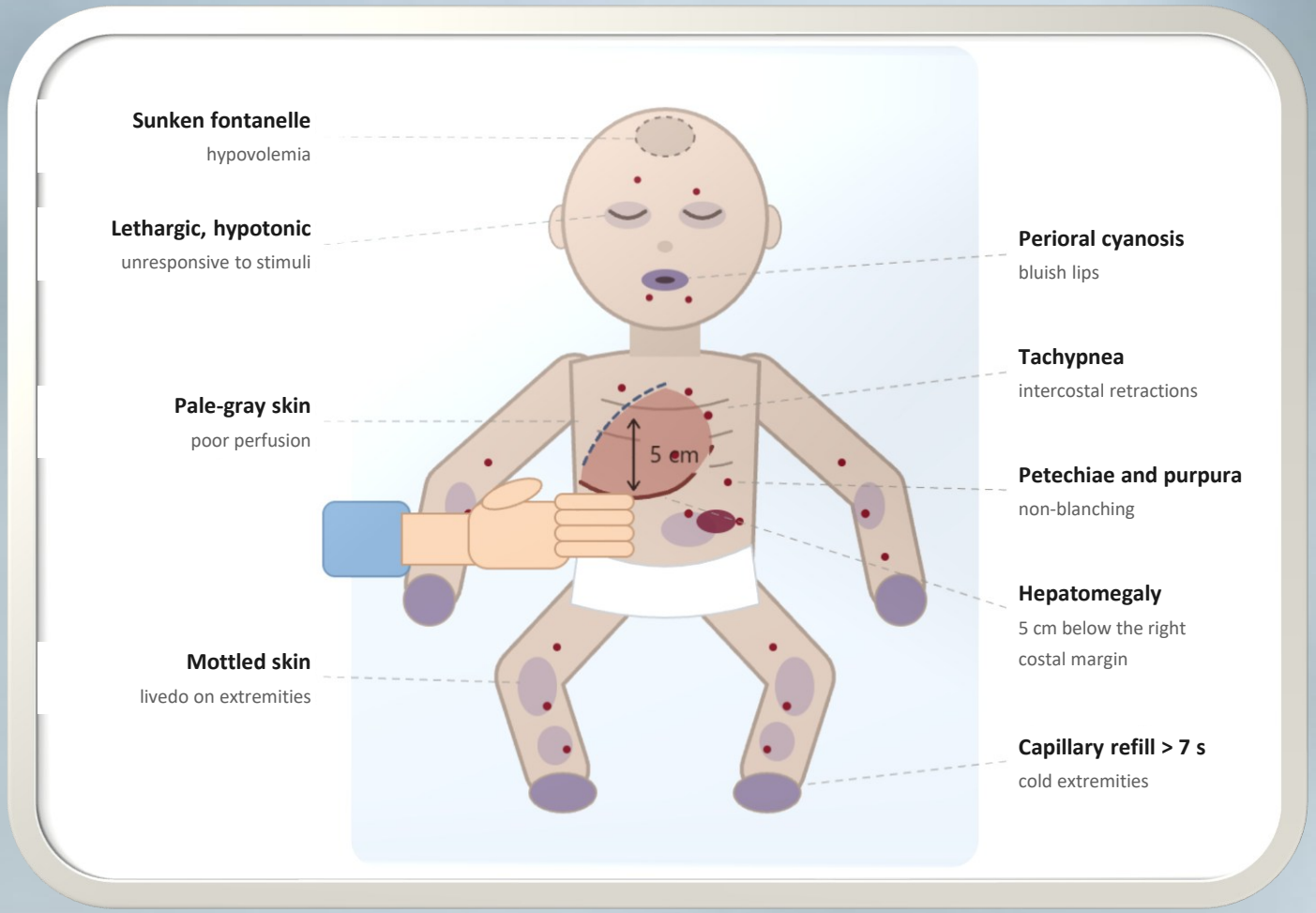
Given the severity, is there myocardial depression?

Are preload, contractility and/or afterload adequate?

Febrile toddler, 1 year 9 months old

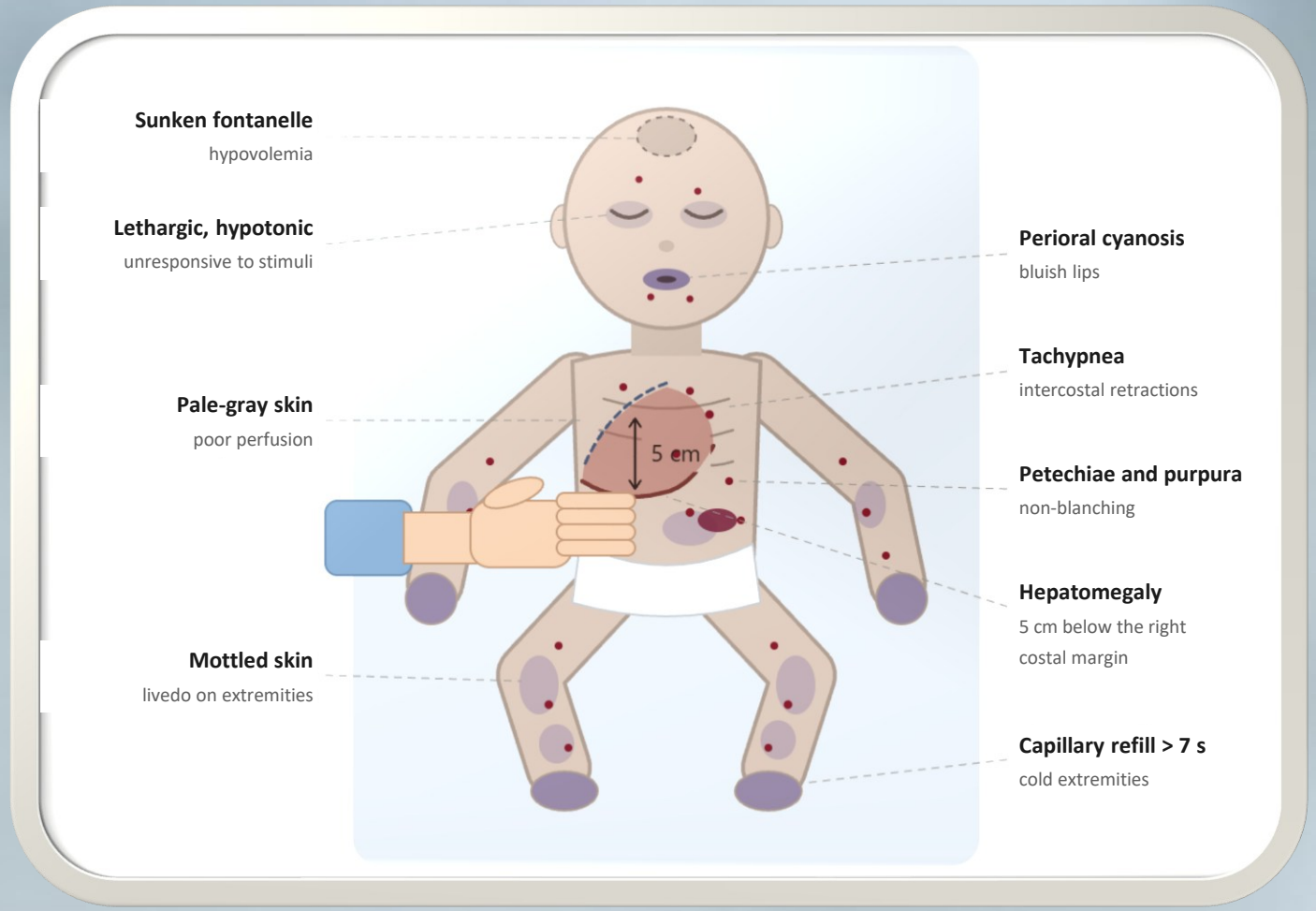
weight: 11,900 g height: 89 cm

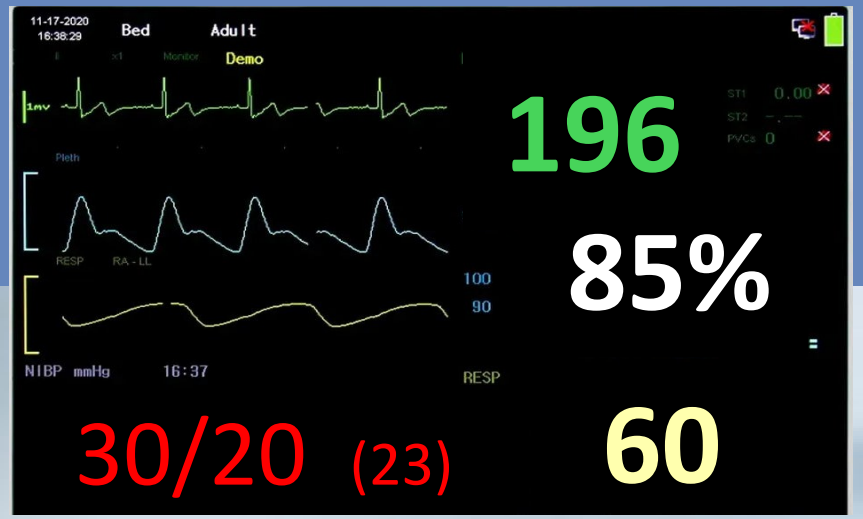




“A real situation that poses great challenges”

“The questions are the same”





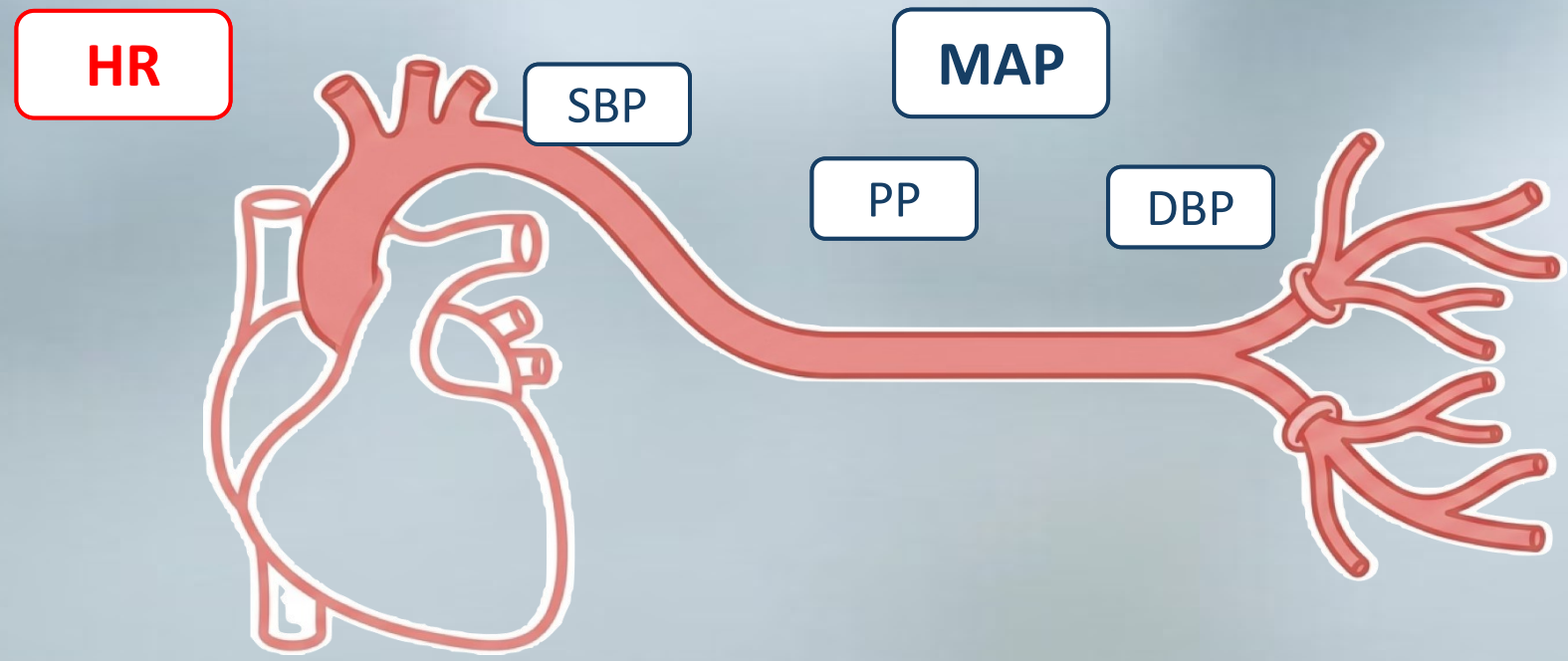
Given the blood pressure we see, is flow adequate?

Will the patient respond to fluid expansion?

Given the severity, is there myocardial depression?

Are preload, contractility and/or afterload adequate?

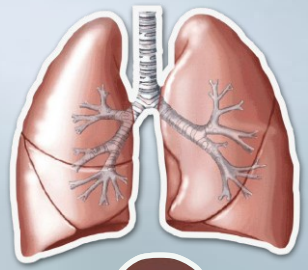
Clinical monitoring in septic shock (SSC 2026)



Perfusion signs



Mental status



Work of breathing



Urine output



Capillary refill

Resuscitation of children with sepsis or septic shock should be guided by continuous clinical assessment of hemodynamic markers, including heart rate, blood pressure, capillary refill time, extremity temperature, pulse quality, level of consciousness and urine output.

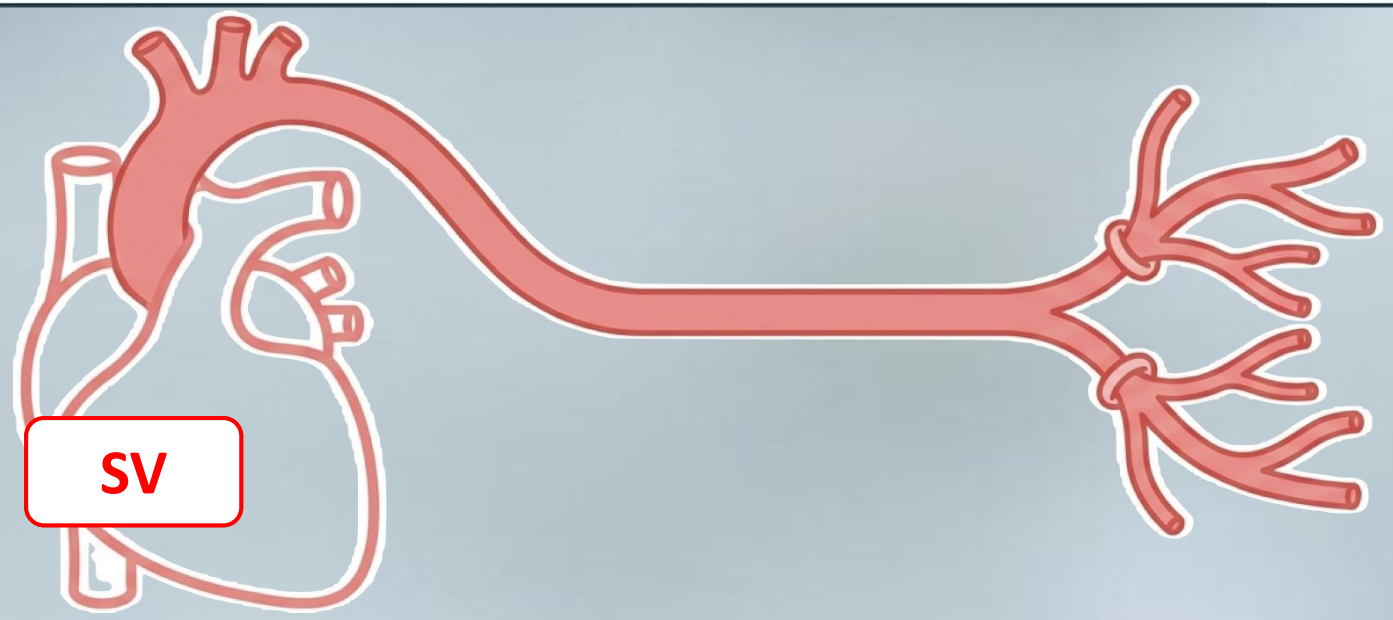
Pediatric Critical Care Medicine 27(4):p 379-434, April 2026.

Why measure cardiac output?



Cardiac output is stroke volume per minute

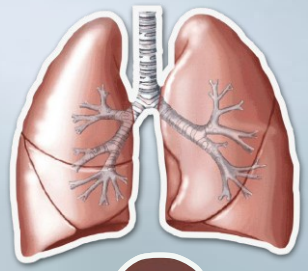
$$HR \times SV = CO = \frac{(MAP - CVP)}{SVR} \times 80$$



Perfusion signs



Mental status



Work of breathing

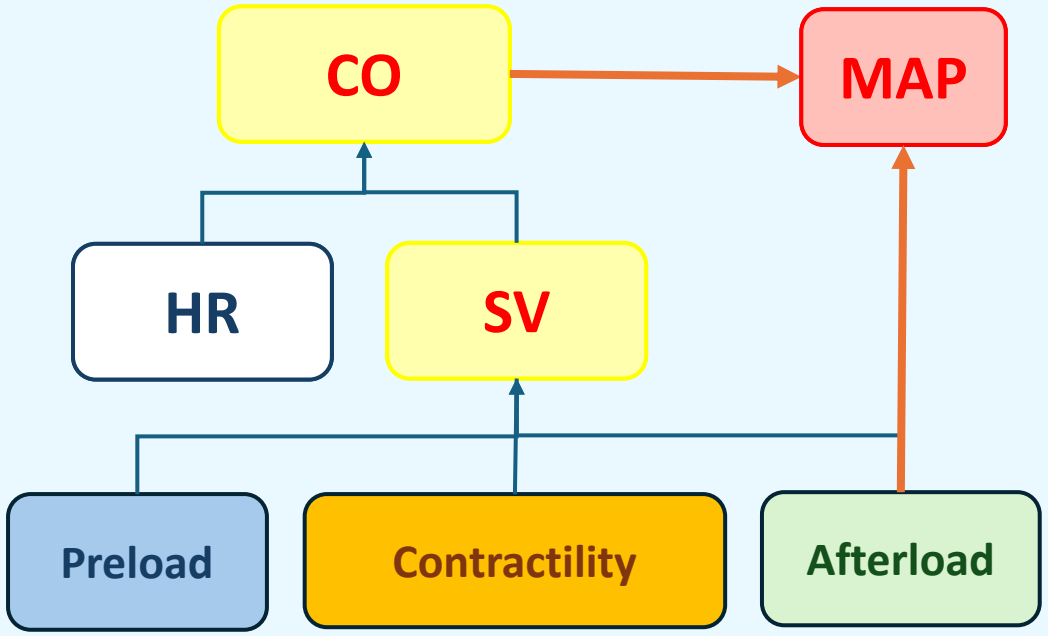


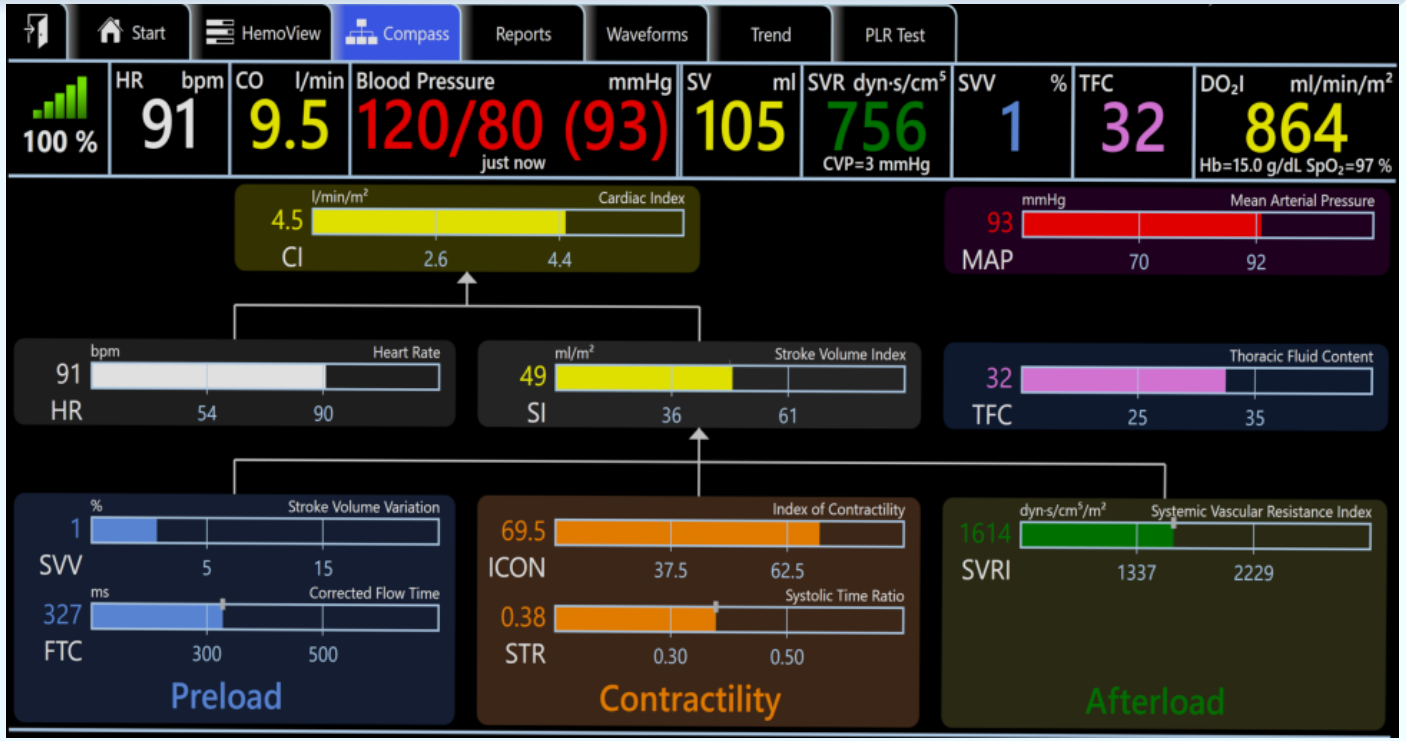
Urine output



Capillary refill

Cardiac output according to the Frank-Starling law



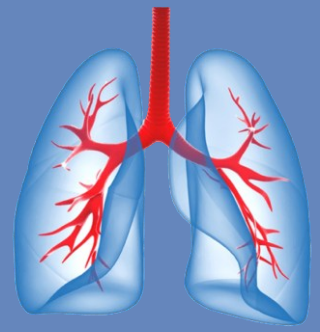


SVV
FTC

ICON
STR

SVR

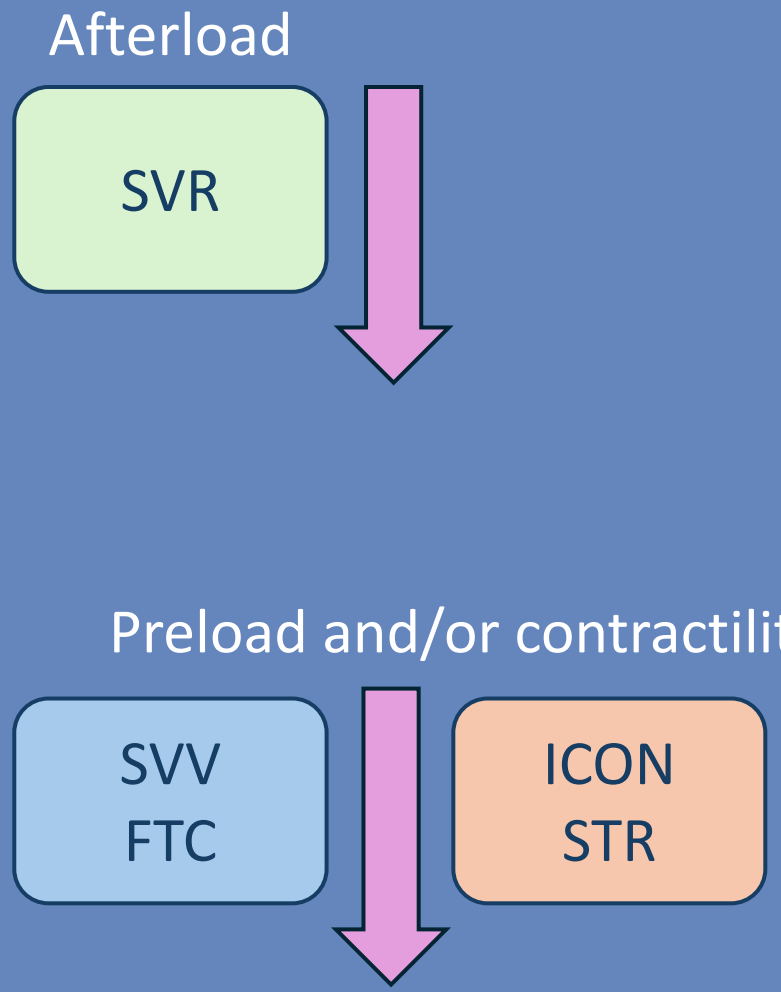
TFC



Hypoperfusion

1. Tachycardia with/without hypotension
2. Cardiac output:

   Increased SV high or normal



Hypoperfusion

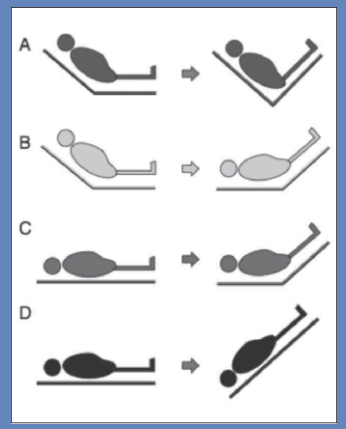
1. Tachycardia with/without hypotension
2. Cardiac output:

Increased	SV high or normal
Normal Low	SV low

Preload and/or contractility

SVV
FTC

ICON
STR

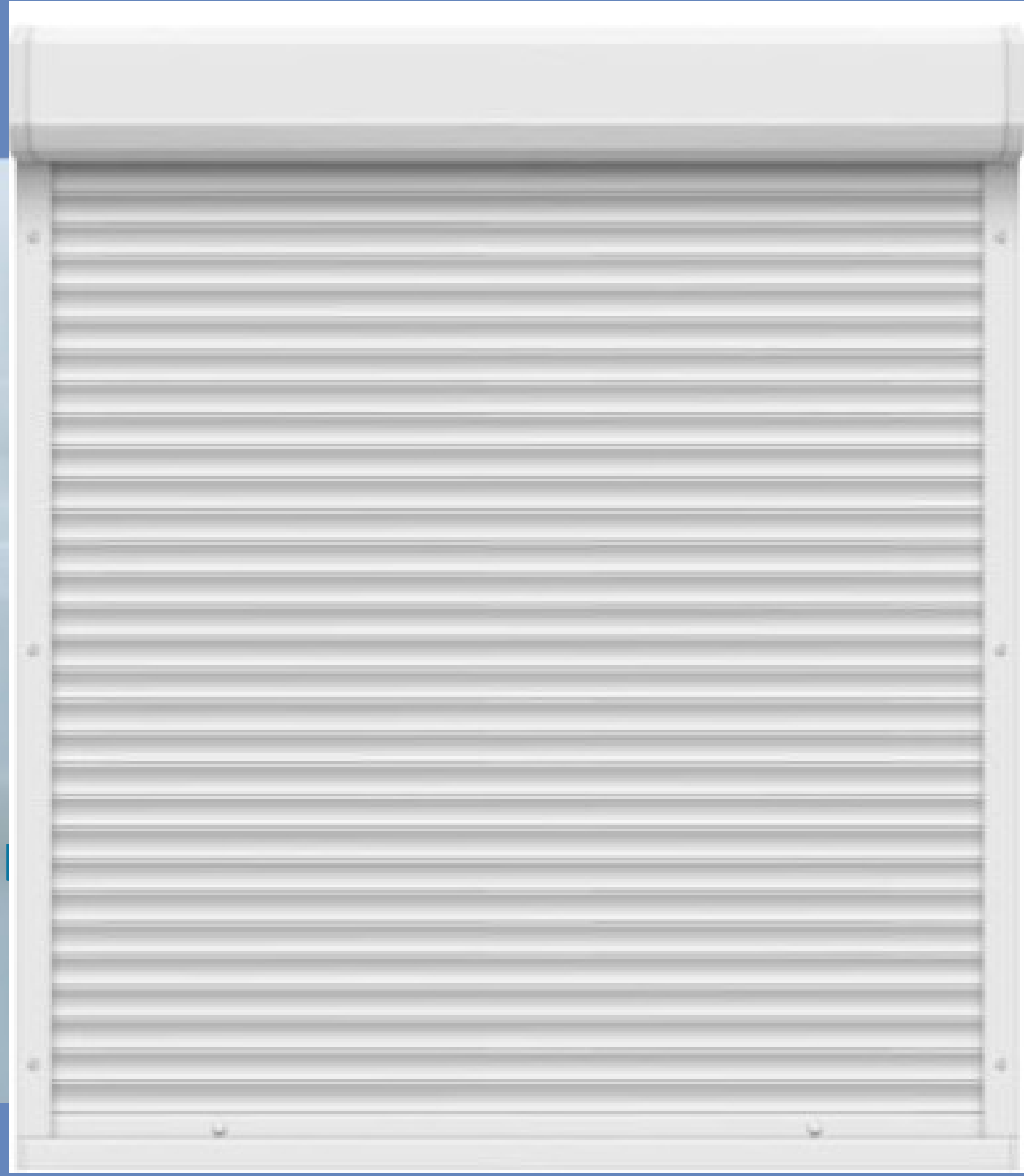


Afterload

SVR

How do we open the window to precision?

We open it with a
non-invasive cardiac output monito

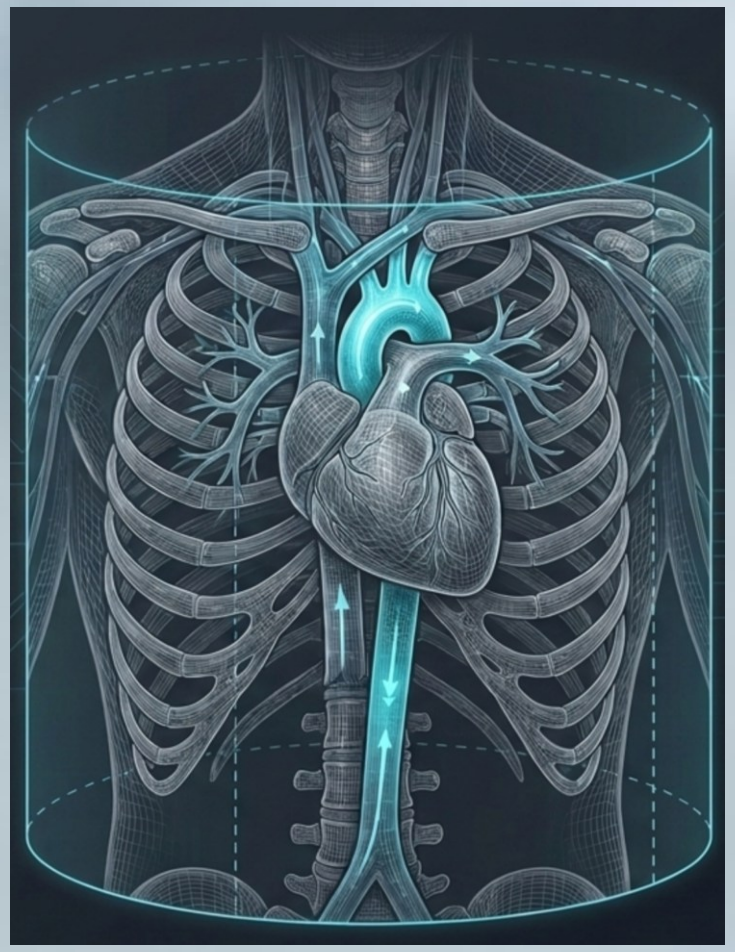


What can we demand from the technology?

- Non-invasive
- Continuous measurement
- Operator-independent
- Self-calibrating
- Low consumables cost
- Battery-operated
- Easy to transport
- Usable at any age
- Usable in any clinical setting



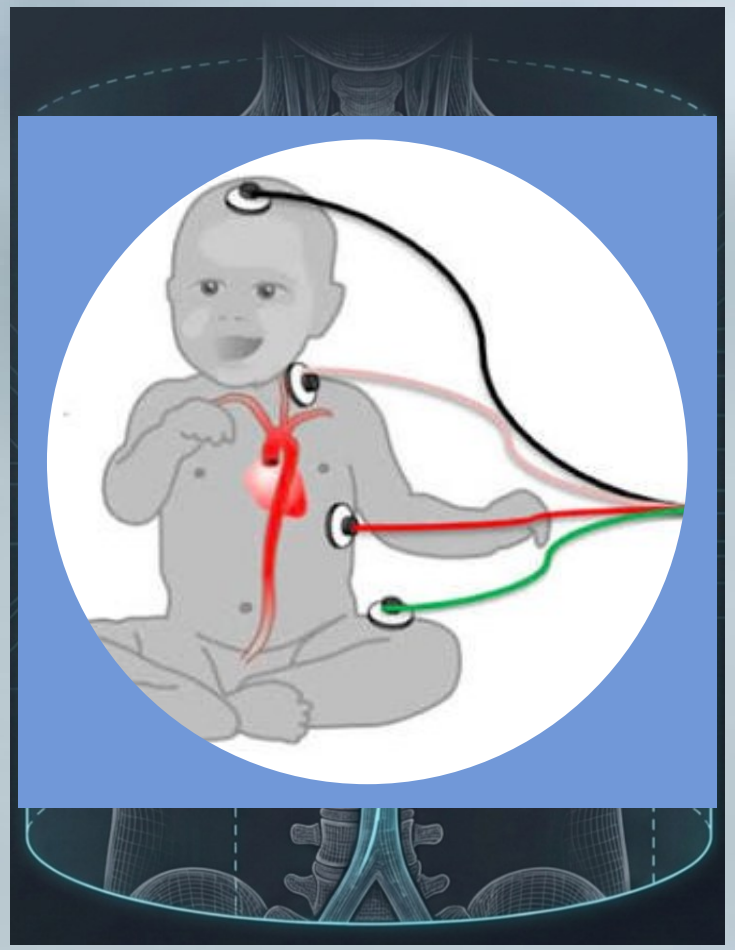
Thoracic electrical impedance

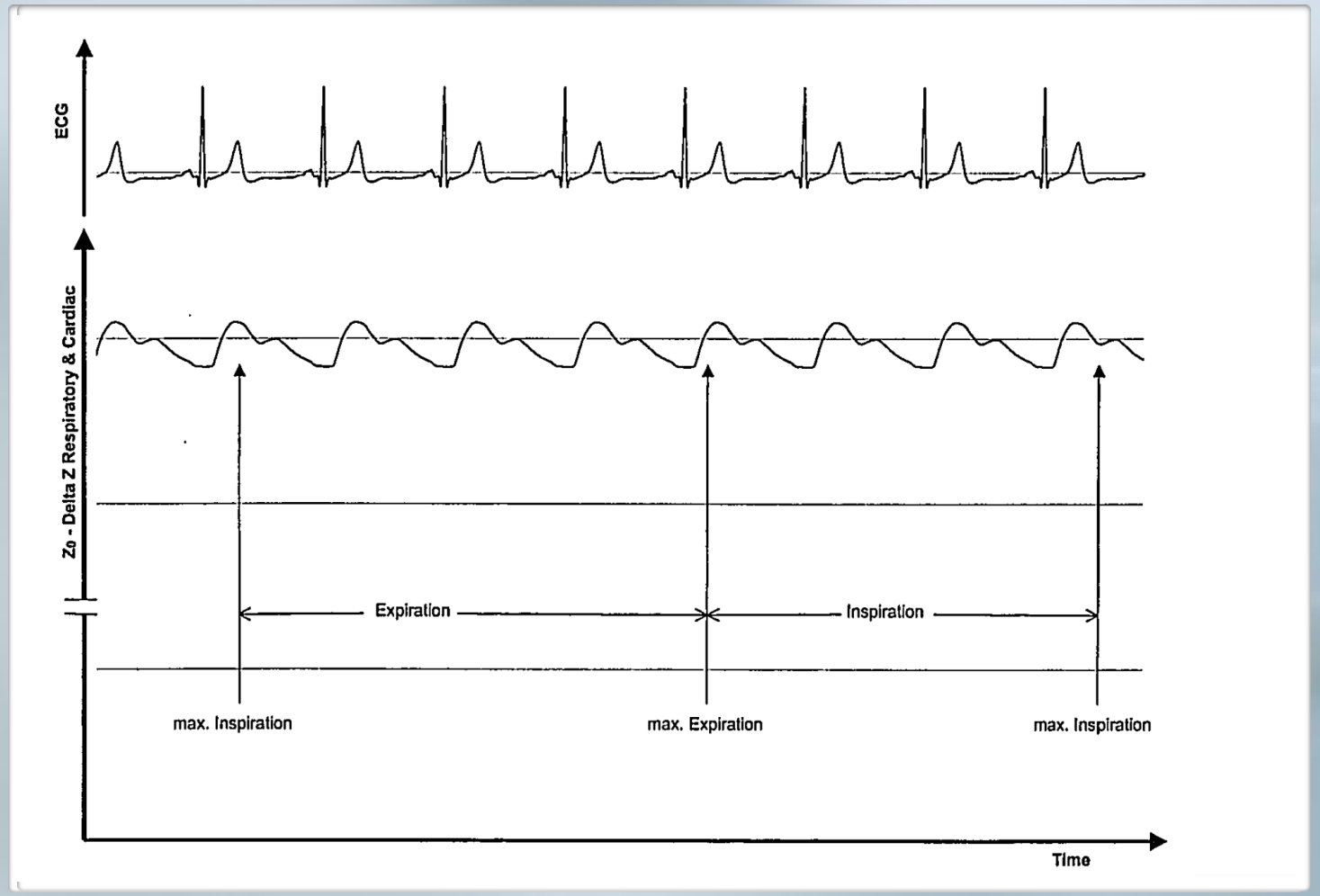


The technology is based on the physical principle of the resistance that biological tissues offer to electrical current:

- Respiratory and cardiac oscillations both affect impedance
- Respiratory oscillations have lower frequency and high impedance (air is a poor conductor)
- Blood oscillations have lower impedance (better conductor) and higher frequencies

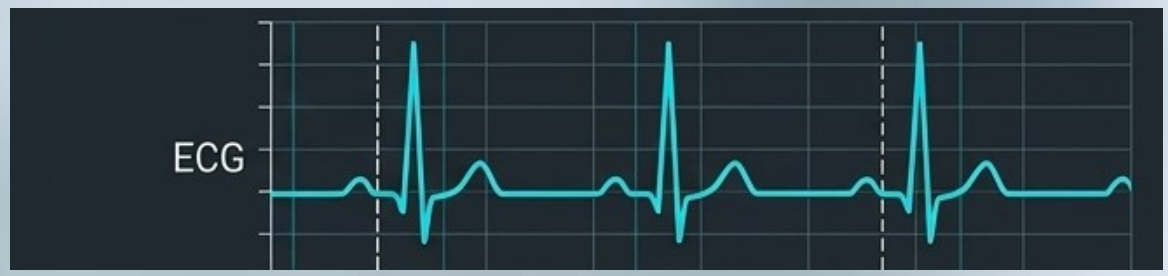
How the continuous analysis signal is obtained

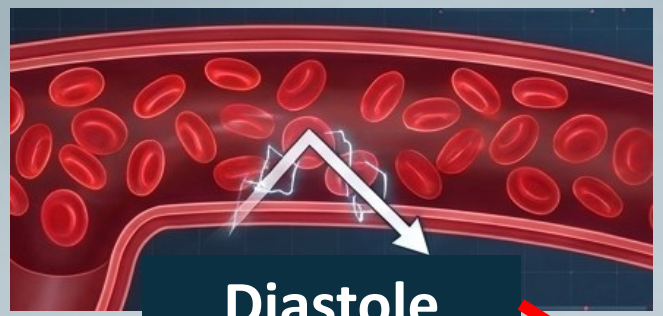




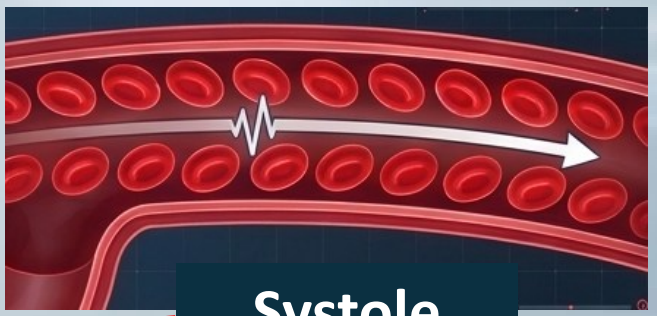
Osypka M. AACN Clinical Issues 10(3): 385-399; 1999.

Electrical velocimetry = $dZ(t)/dt_{max}$





Diastole

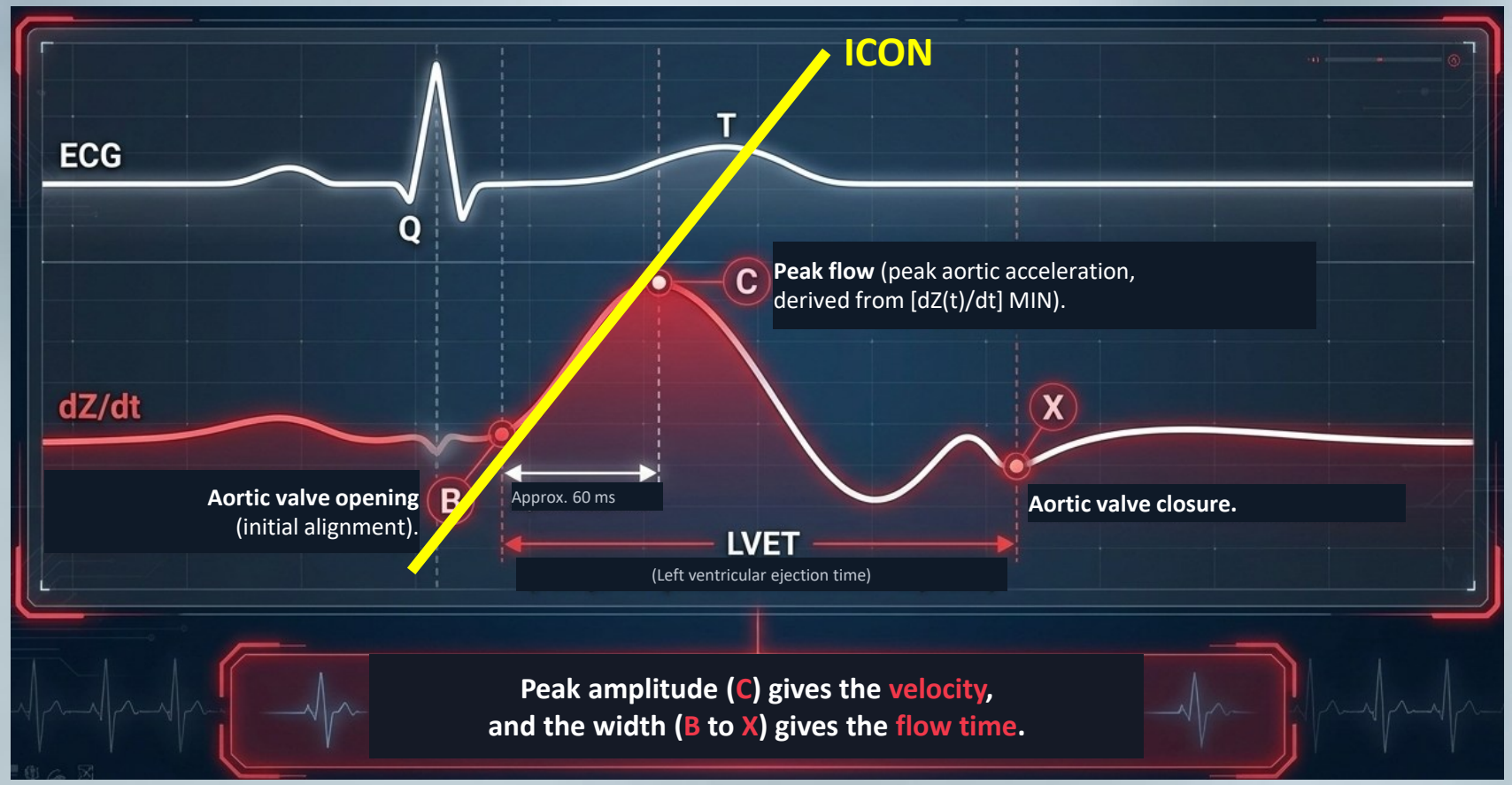


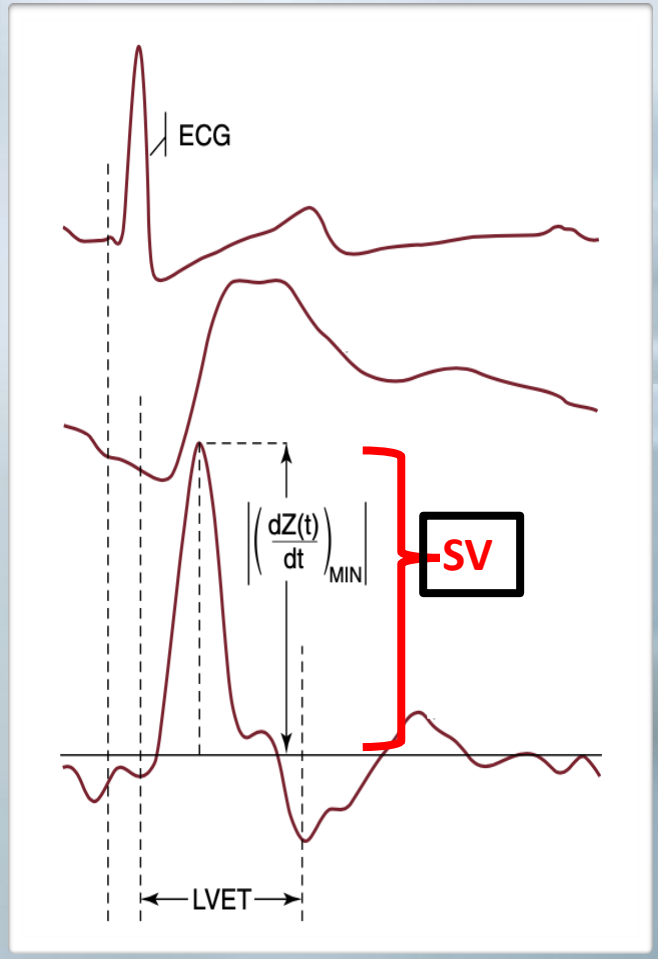
Systole



Peak acceleration of blood at the aortic inlet

Anatomy of the waveform of impedance change over time





Bernstein-Osypka equation

Stroke volume (SV)

$$SV = V_{EPT} \times V_{Aorta} \times FTC$$

Patient constant – V_{EPT}

- Volume of electrically participating tissue.
- Derived from anthropometric variables: weight and height.

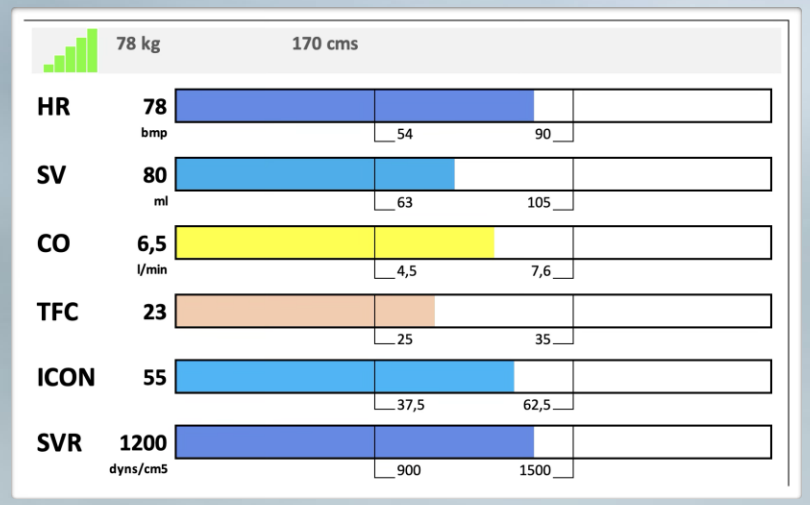
Peak aortic acceleration – v_{AORTA}

- Mean blood velocity.
- Derived mathematically from the magnitude of point C on the dZ/dt waveform.

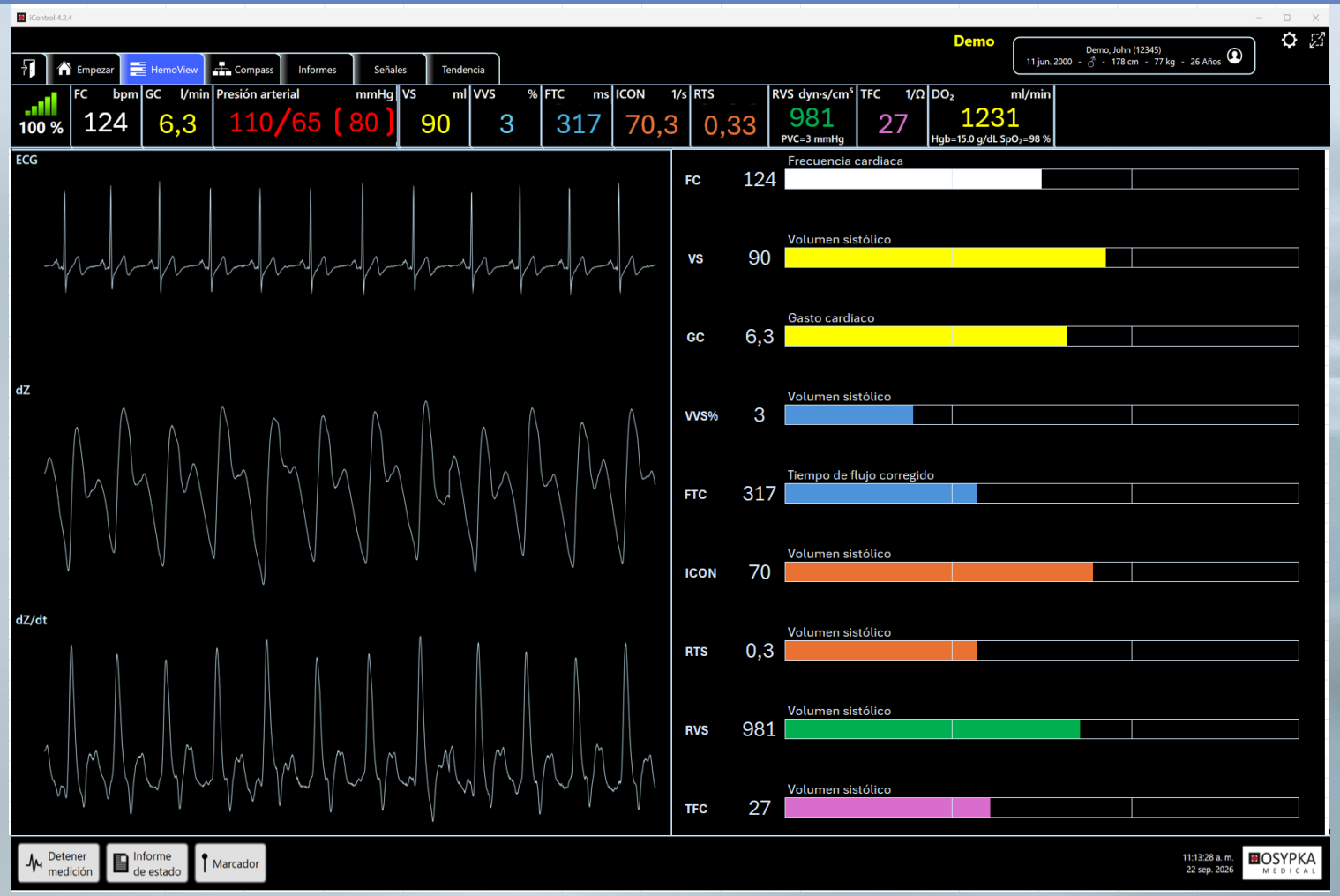
Flow time – FT_C

- Left ventricular ejection time (LVET), measured between points B and X.
- Corrected for heart rate (R-R interval).

On-screen parameters HemoView® on IControl®

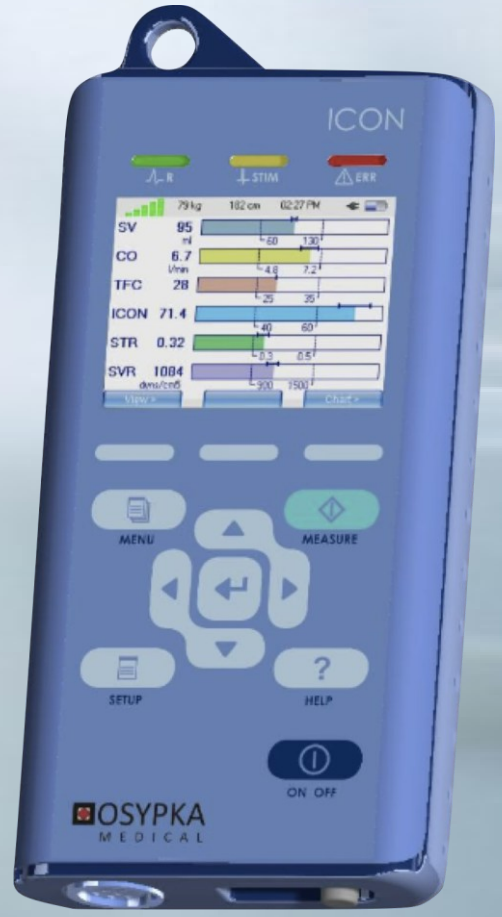






Parameters provided by the device

Manually entered parameters		Directly measured parameters		Calculated parameters		Parameters indexed to body surface area	
Age	Sex	HR	Heart rate			BSA	
Weight	Height	SV	Stroke volume			SI	Stroke index
		CO	Cardiac output			CI	Cardiac index
		SVV	Stroke volume variation				
		FTC	Systolic flow time corrected for heart rate				
		LVET	Left ventricular ejection time				
		ICON	Index of contractility			CPI	Cardiac power index
		STR	Systolic time ratio				
		PEP	Pre-ejection period				
SBP	DBP	TFC	Thoracic fluid content			MAP	
	CVP			SVR	Systemic vascular resistance	SVRI	Systemic vascular resistance index
Hb	O2 sat			CaO2	Arterial oxygen content		
				DO2	Oxygen delivery	DO2I	Oxygen delivery index



Clinical prerequisites for accuracy



Chest integrity

The chest must be intact. Not usable in open-chest patients (massively alters bioelectrical conductance)

Positioning

The patient must be supine and at rest (not talking, no sudden head movements)

Sensor quality

Requires in-date, well-hydrated (not dry) **Osypka** Ag/AgCl surface sensors

Entering exact height and weight is mandatory to calculate indexed values correctly.

Problems that affect accuracy



Arrhythmias
especially atrial fibrillation



Extreme obesity



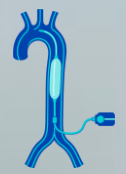
Significant aortic regurgitation



Open chest



Intracardiac shunts



Intra-aortic balloon pump

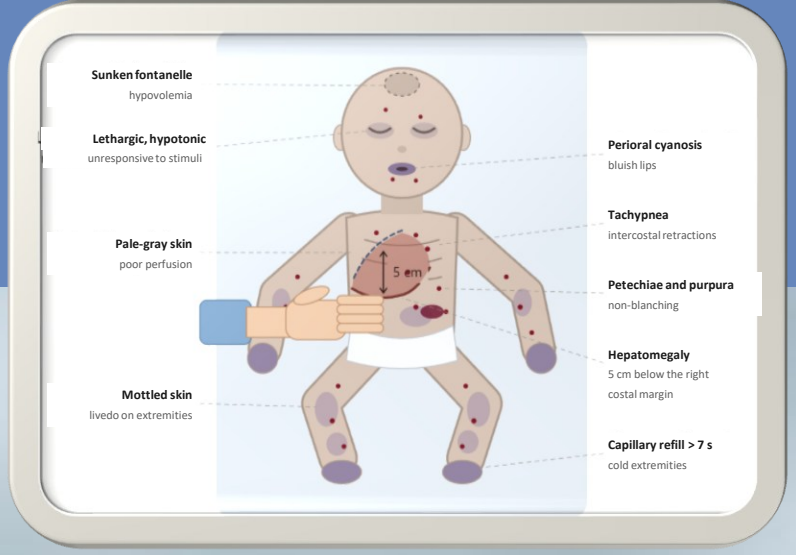


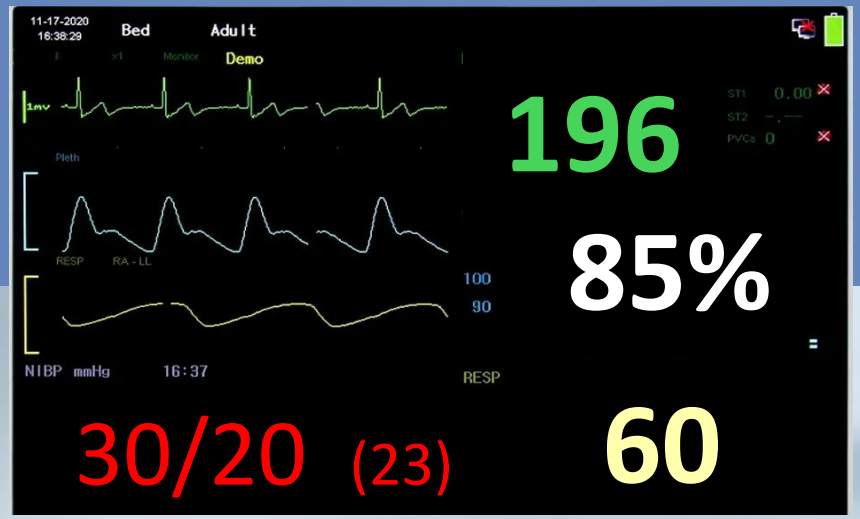
Large pleural effusion or pulmonary edema



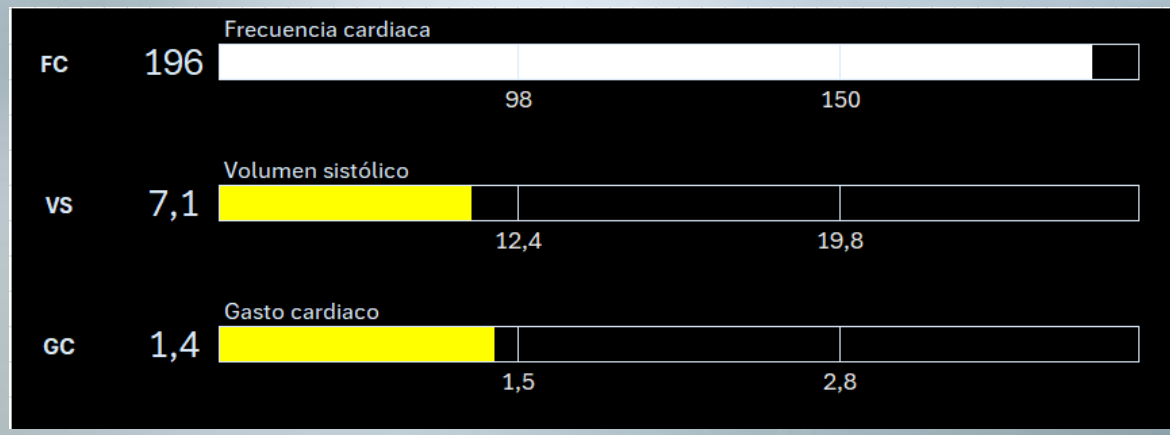
Use of electrocautery
during measurement

Septic shock



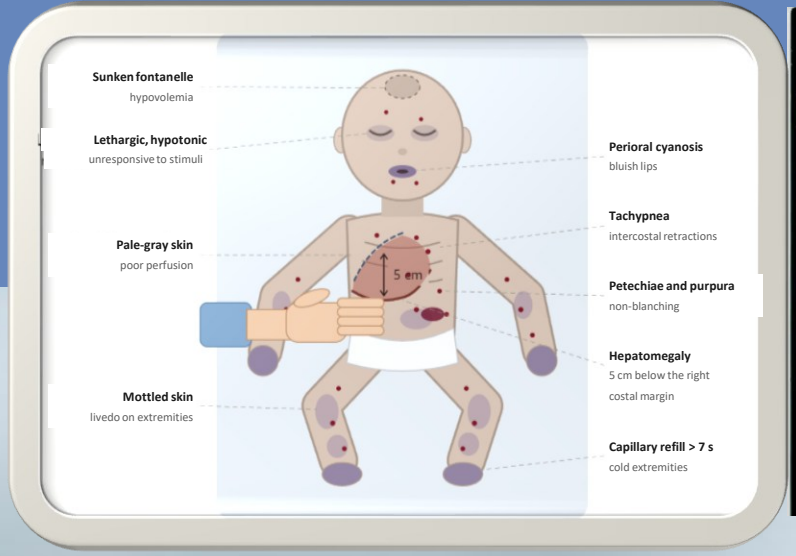


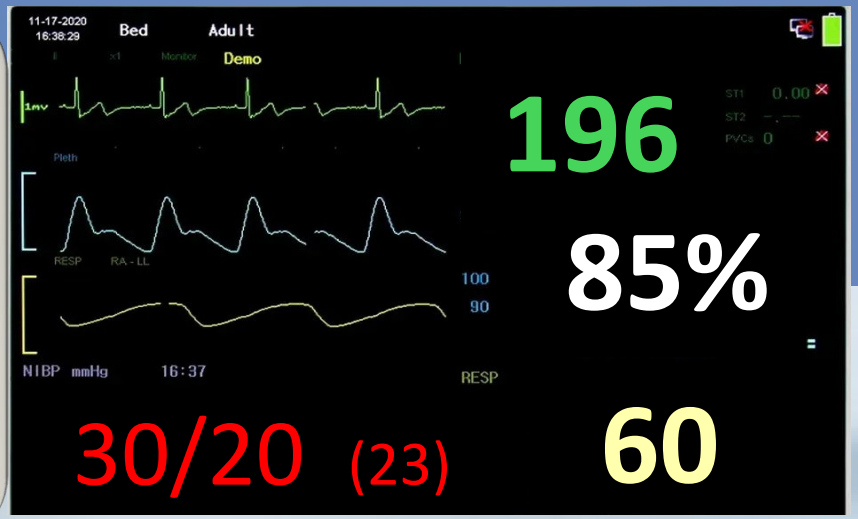
What is their cardiac output?



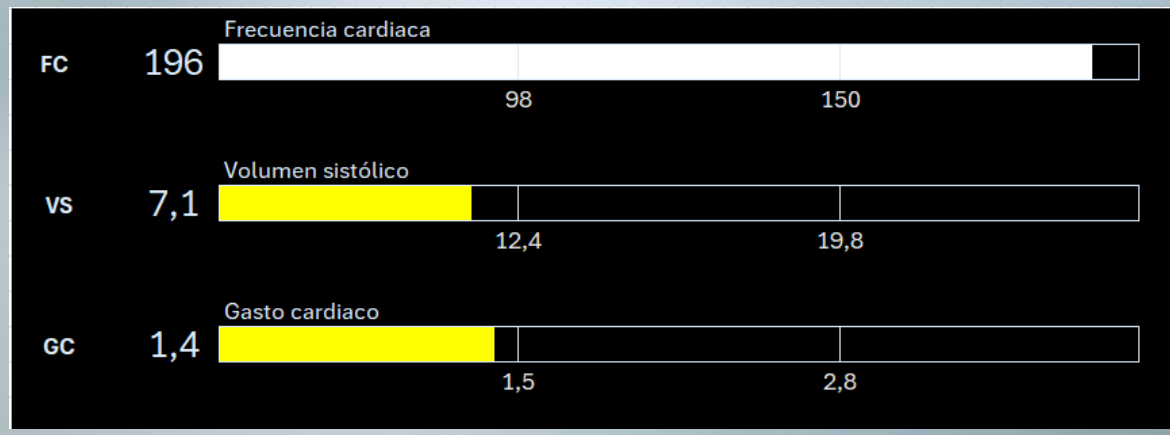
Septic shock

with low CO





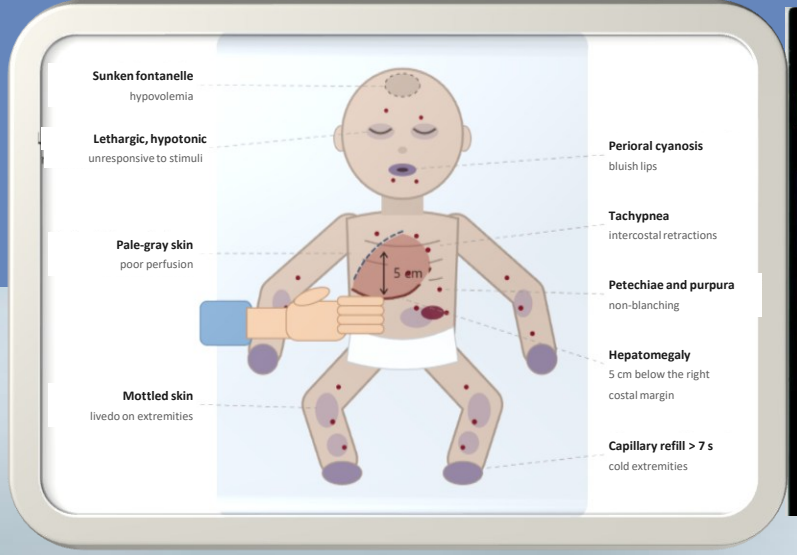
What is their systemic vascular resistance?

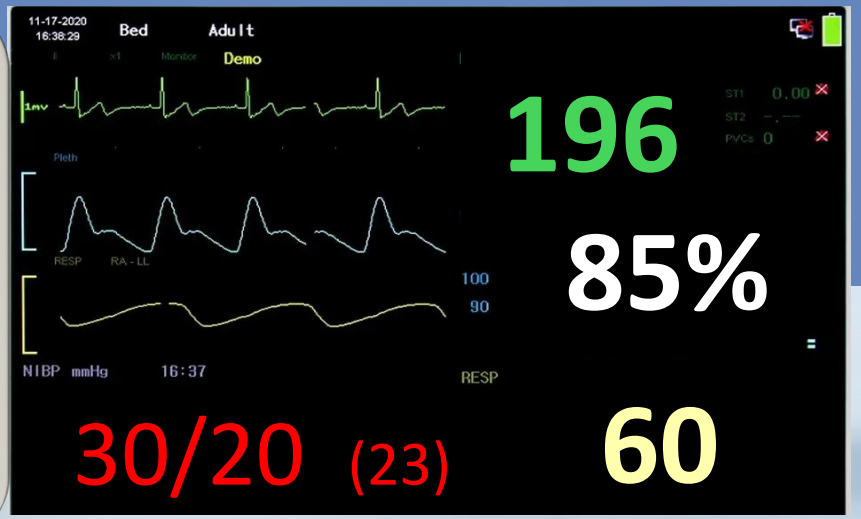


$$SVR = \frac{(MAP - CVP) \times 80}{CO}$$

Septic shock

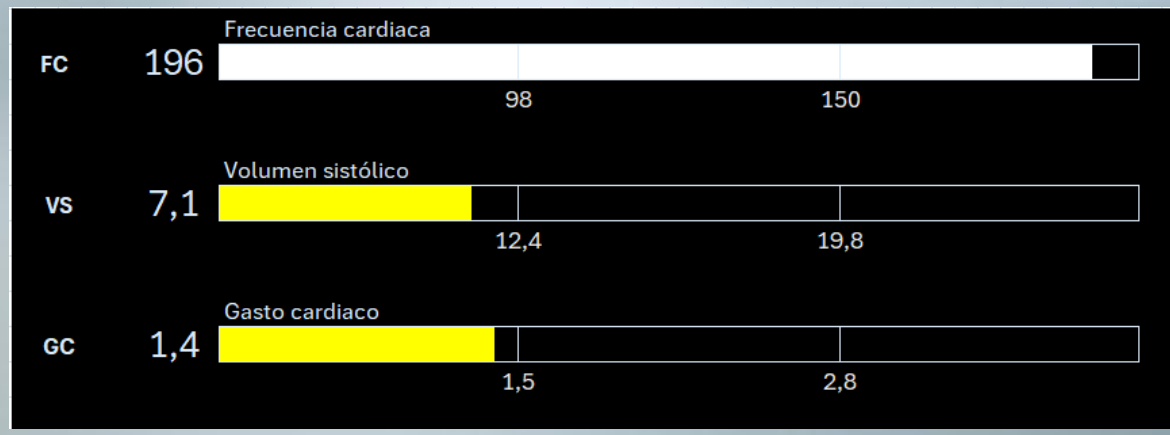
with low CO

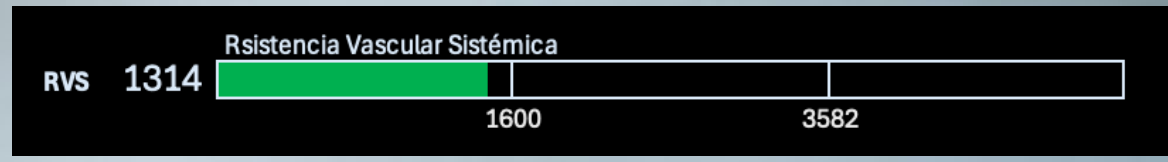




What is their SVR?
with CVP = 0

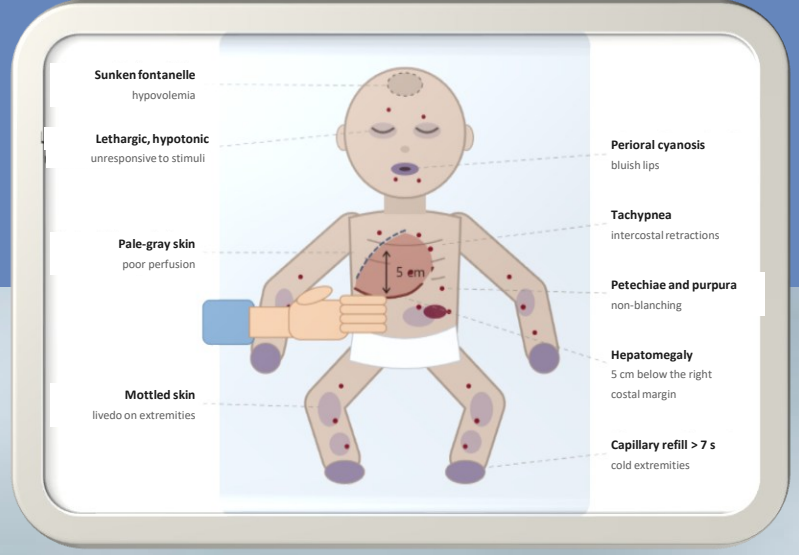
$$SVR = \frac{(MAP - 0) \times 80}{CO}$$

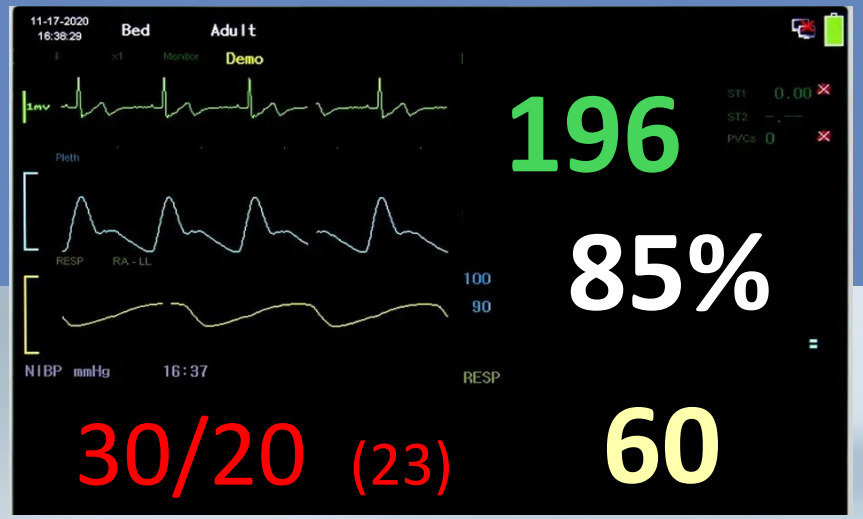




Septic shock

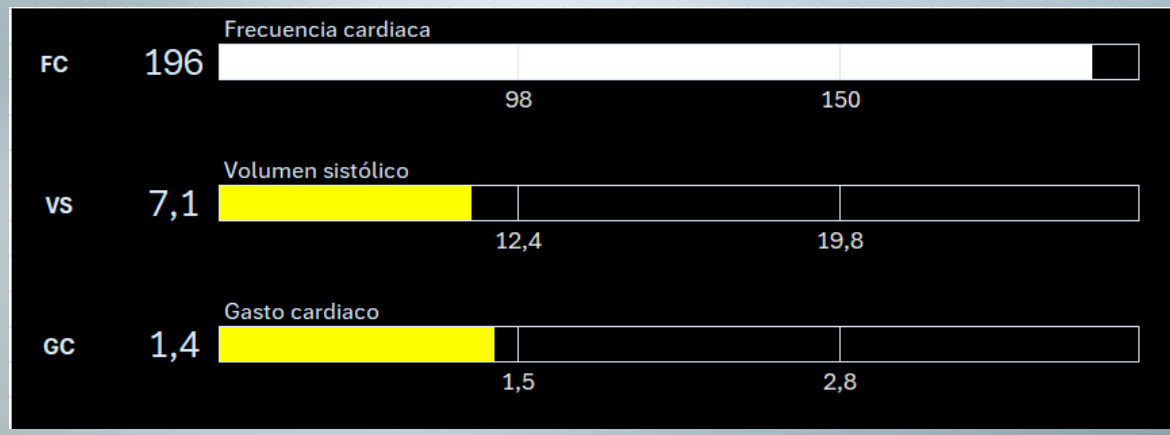
with low CO





What is their SVR?
with CVP = 5

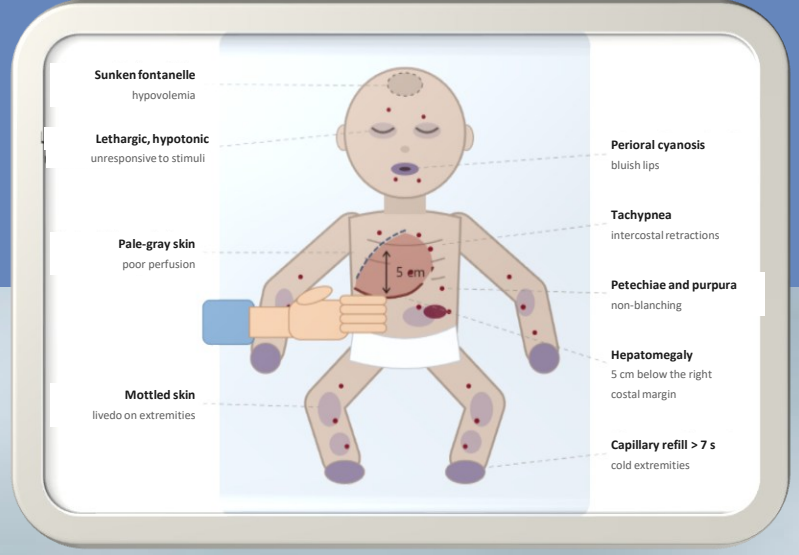
$$SVR = \frac{(MAP - 5) \times 80}{CO}$$

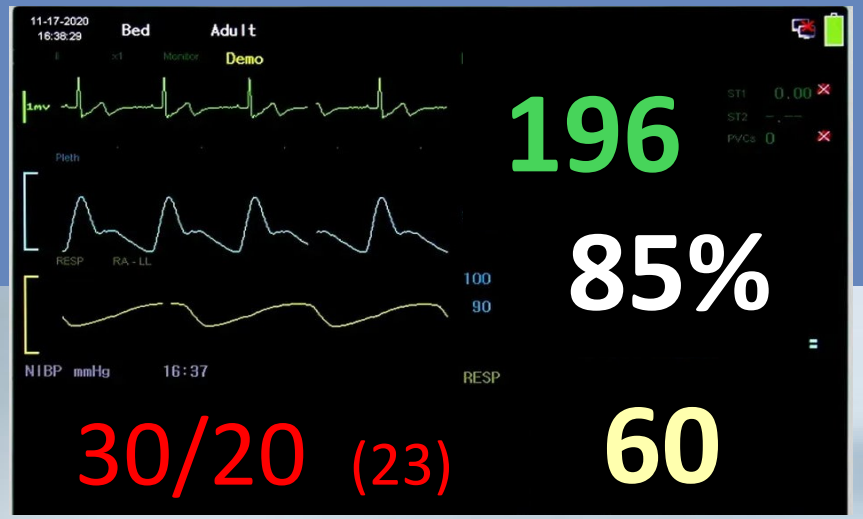




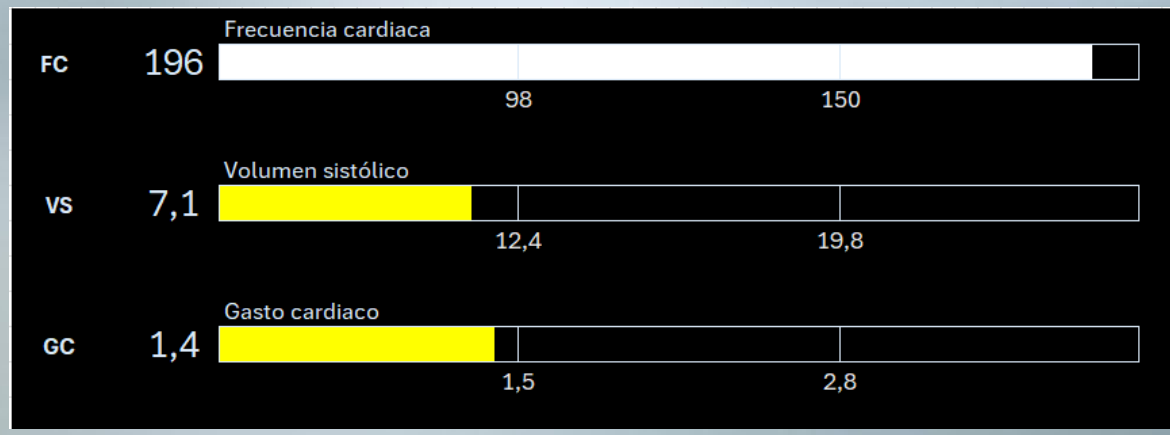
Septic shock

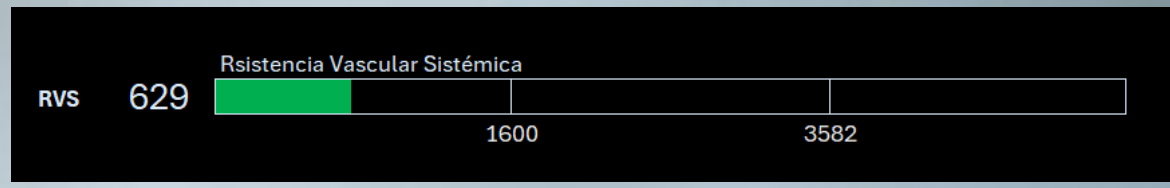
with
low CO and SVR





What would be the indications?





$$SVR = \frac{(MAP - 12) \times 80}{CO}$$

Septic shock with low CO and SVR

Indications:

1. Volume



2. Inotrope



3. Vasopressor



For appropriate initial hemodynamic management,

Do we rely on clinical signs alone

or

add non-invasive measurements?



Ranjit 2014 · *48 children aged 1 month to 16 years, 2 PICUs in India, 2009–2012*

Categorize the hemodynamic profile of children with septic shock refractory to fluids (> 40 mL/kg) using multimodal monitoring, and adjust therapy to the findings

Clinical examination

Cold or warm shock by peripheral perfusion

Invasive arterial pressure

Vasodilated or vasoconstricted shock by **pulse pressure and diastolic pressure**

Focused echocardiography

Volume status (IVC), ventricular function and tamponade

Secondary objective: describe the clinical features of septic myocardial dysfunction in children.

Ranjit S, et al. Pediatr Crit Care Med 2014;15(1):e17–e26

Results (Ranjit 2014)

196

30/20 (23)

85.4%
vasodilated by invasive arterial pressure (41/48)

67%
of clinically cold shocks were vasodilated (14/21)

39.6%
septic myocardial dysfunction, LV ± RV (19/48)

33%
persistent hypovolemia, IVC collapse > 50% (16/48)

Therapy changed in **87.5%** after echo and invasive BP · shock resolved in **96%** · survival: **91.7%**

CONCLUSION

Physical examination is not enough to determine the hemodynamic profile.
Echo reveals myocardial dysfunction and **hypovolemia that clinical signs miss**, and invasive pressure shows vasodilation.
Shock that does not resolve may reflect poorly chosen support rather than truly refractory shock.

Ranjit S, et al. Pediatr Crit Care Med 2014;15(1):e17–e26

Razavi 2017 · 40 children, *PICU at Children's Hospital Los Angeles, 2013–14*

Assess how well physicians estimate cardiac index and systemic vascular resistance in children in shock, compared with an objective measurement (USCOM)

Clinical assessment

2 to 3 physicians classified CI and SVRI as low, normal or high using examination, vital signs and labs

Objective measurement

USCOM: continuous-wave transthoracic Doppler of aortic flow, blinded to physicians

Cut-offs

CI low < 3.5 and high > 5.5
SVRI low < 800 and high > 1,600

Also: measure agreement between physicians and explore whether clinical decisions would change with USCOM data.

Razavi *A, et al. J Crit Care 2017;39:6–10*

Results (Razavi 2017)

48.5%
clinical accuracy for cardiac index (κ = 0.18)

45.9%
clinical accuracy for vascular resistance (κ = 0.16)

58.7%
agreement between two physicians on CI (κ = 0.33)

21%
unacceptable indications per USCOM (56/268)



Physicians underestimated CI and overestimated resistance:
- low CI in **22%** vs 4% by USCOM
- high SVRI in **29%** vs 7% by USCOM
- Attending physicians were no more accurate than residents

CONCLUSION

Clinical examination poorly estimates output and resistance in children in shock, regardless of physician experience, and inter-physician variability is high.
Objective measurement could reduce treatment errors.

Razavi A, et al. J Crit Care 2017;39:6–10

What does a resident need?

- A single measurement used as a reference for long-term comparison demands more accuracy, but that is not necessarily the goal in critical care
- What the resident needs to optimize monitoring is how the measurement changes over time and responds to interventions or to the patient's course

"Accuracy relative to the gold standard and/or efficiency in detecting changes over time"

"Accuracy relative to the gold standard

and/or

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Dilated cardiomyopathy

12-year-old boy

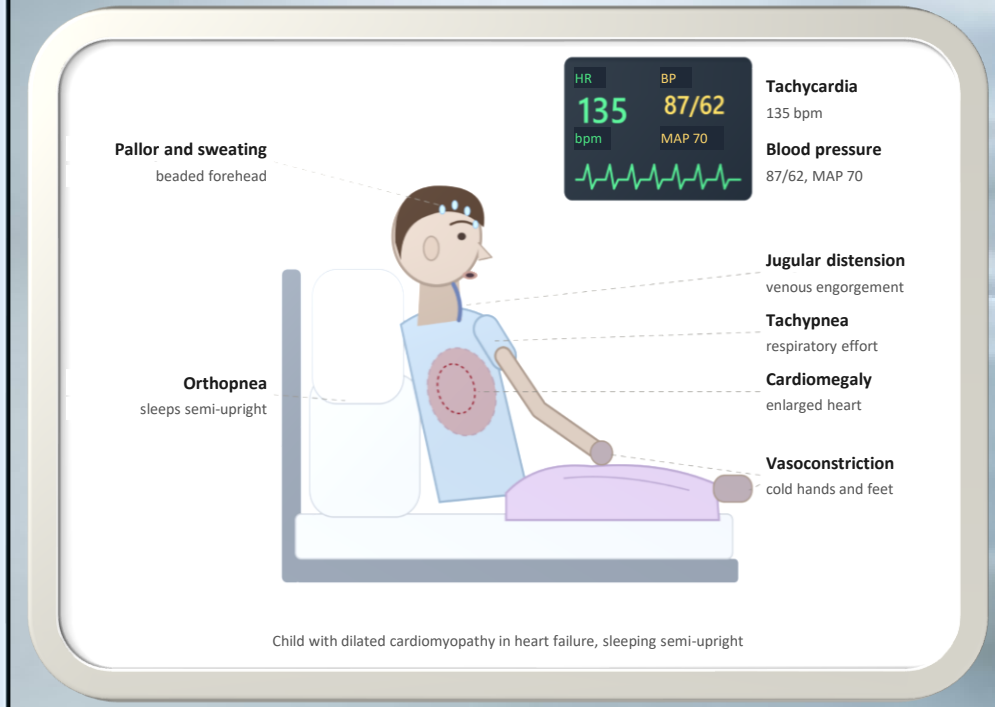
Follow-up echocardiography

- Globular LV, 56 mm (Z-score +3.3)
- LVFS 21%
- LVEF 43%
- Diastolic dysfunction on tissue Doppler
- **Sessile thrombus at the left ventricular apex**

Admitted to start anticoagulation therapy

- Asymptomatic at scheduled follow-up
- Stable hemodynamics

	Feb	Jun
HR	77	135
SBP	105	87
DBP	57	62
MAP	73	70
PP	48	25
SV	90	31
CO	7.0	4.1
SVV	16	24
TFC	33	33
ICON	183	35.6
STR	0.56	1.04
SVR	793	1,347



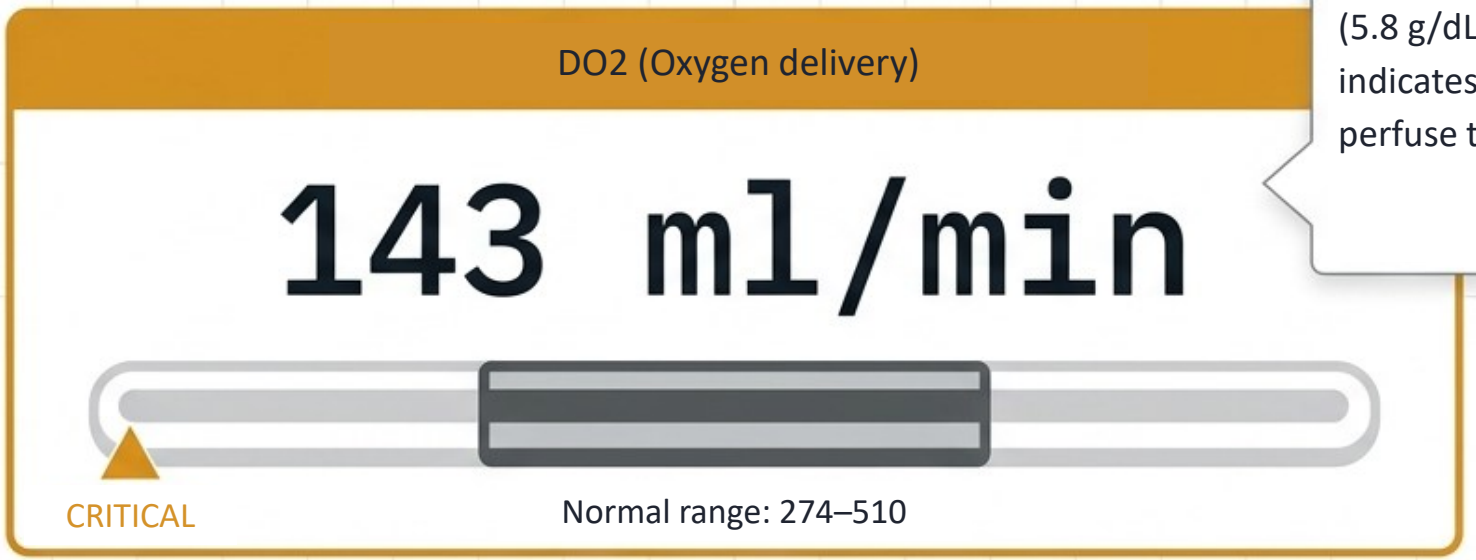
Child with dilated cardiomyopathy in heart failure, sleeping semi-upright

Child with hemolytic uremic syndrome

Age 11 months · Weight 12 kg · Height 82 cm · Hb 5.8 g/dL

Baseline status reveals critical impairment of oxygen delivery to tissues

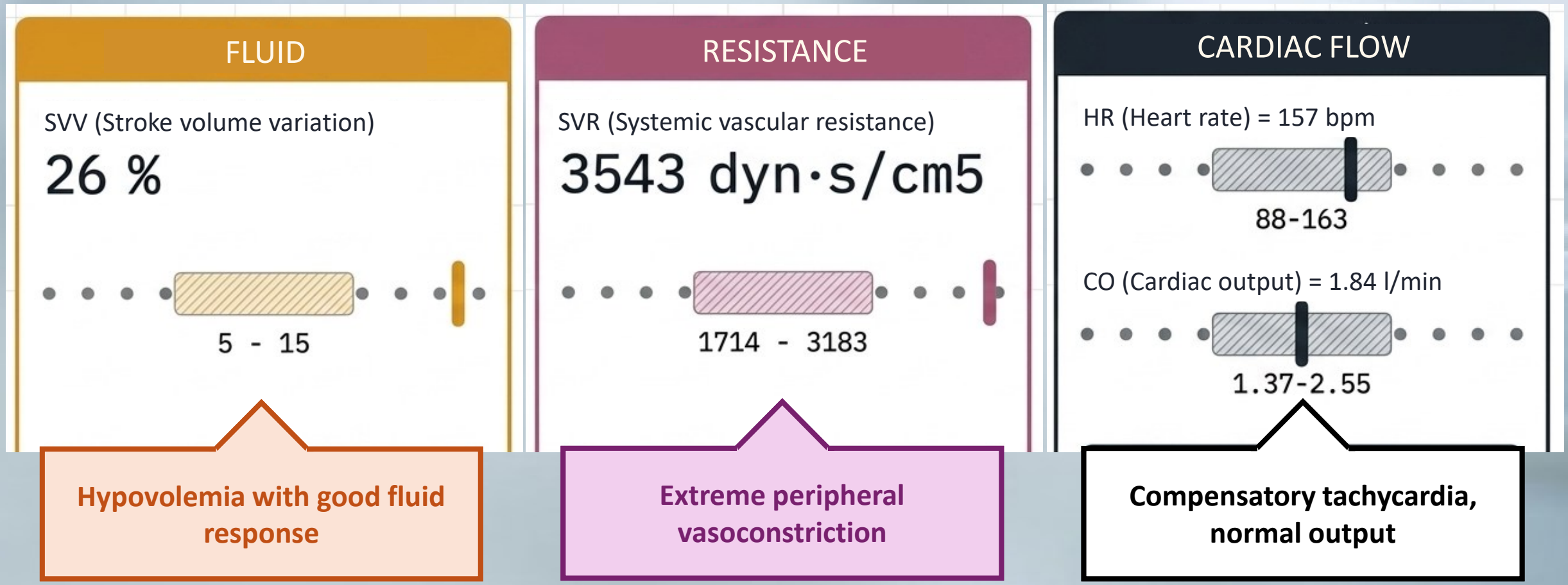
12:15 hrs | Anuric patient with confirmed severe anemia



Severe hemoglobin deficit (5.8 g/dL) combined with anuria indicates a critical inability to perfuse target organs.

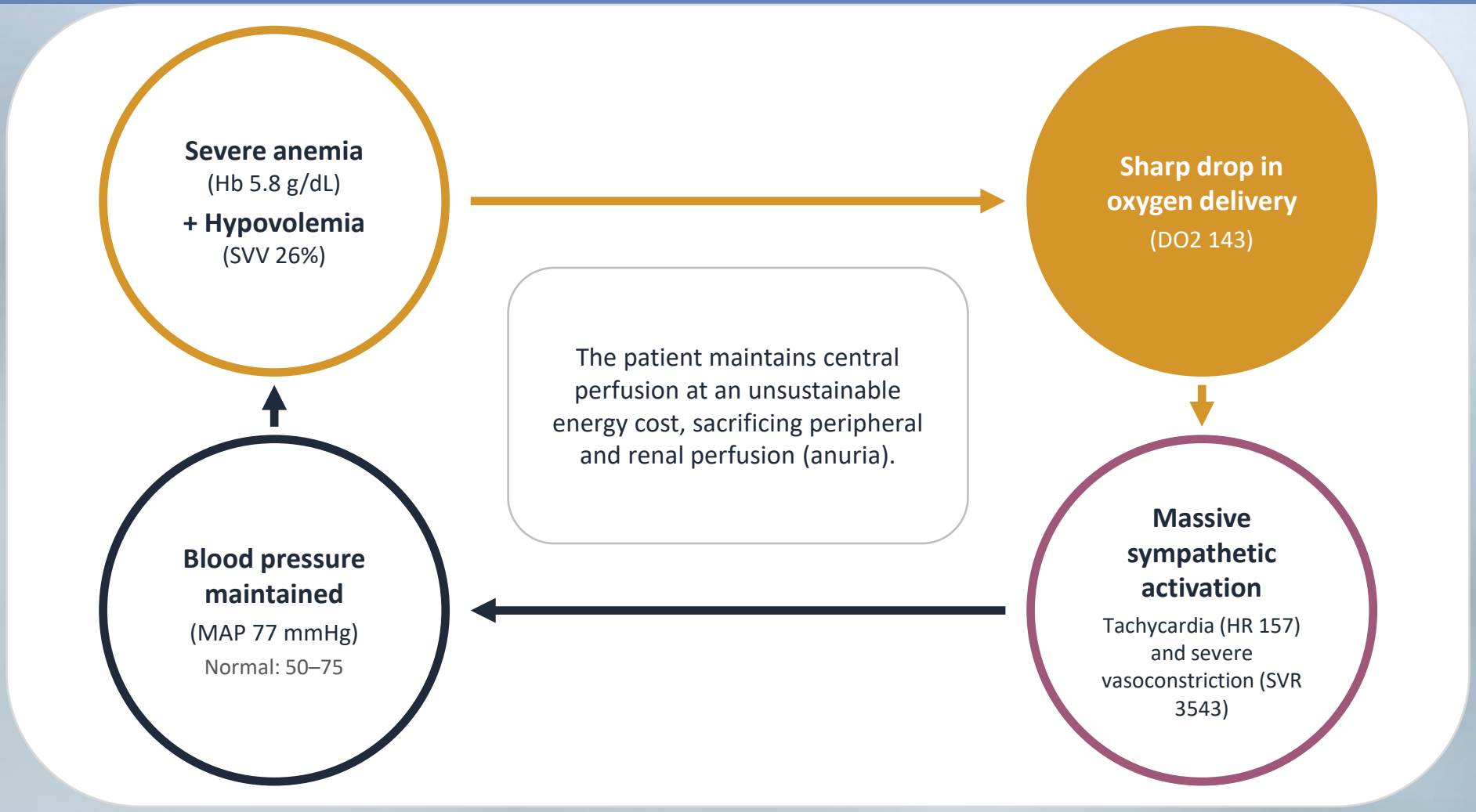
HR: 157 BP: 103/64 (77) PP: 39

Hemodynamic monitoring reveals severe hypovolemia with extreme vasoconstriction



HR: 157 BP: 103/64 (77) PP: 39

The compensation cycle hides impending shock behind an apparently normal blood pressure



Therapeutic intervention aimed at restoring circulating volume and oxygen-carrying capacity

12:15 hrs — Intervention window — 16:14 hrs



Normal saline bolus (NS)

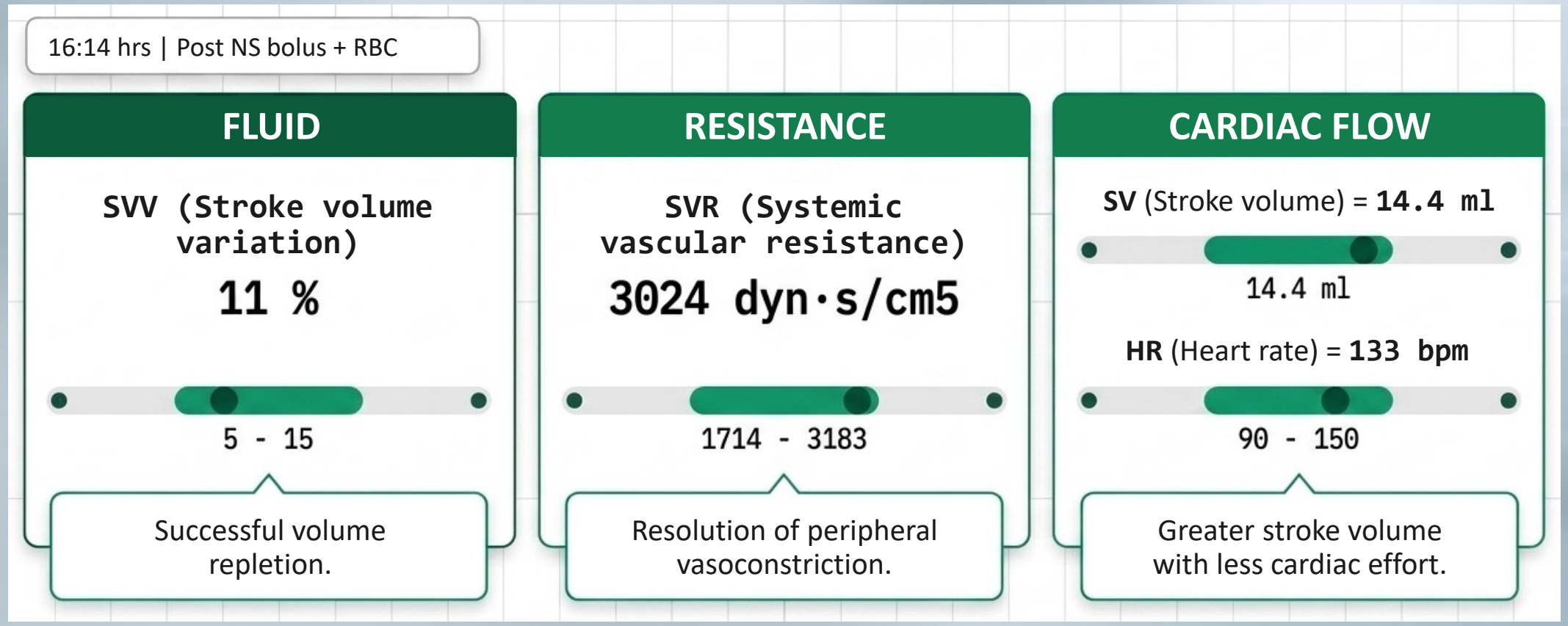
Aimed at correcting hypovolemia (SVV 26%) and expanding intravascular volume.



Red blood cell transfusion (RBC)

Aimed at correcting baseline anemia (Hb 5.8) and increasing oxygen delivery (DO2).

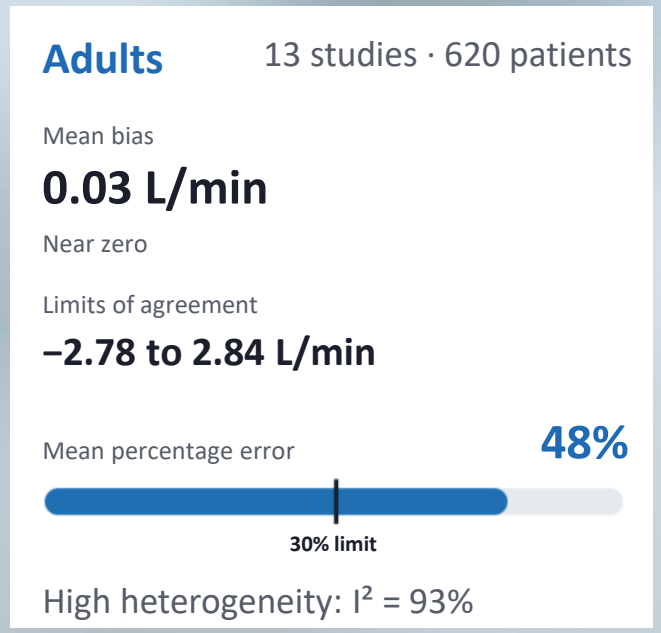
Post-intervention hemodynamics show objective resolution of sympathetic stress

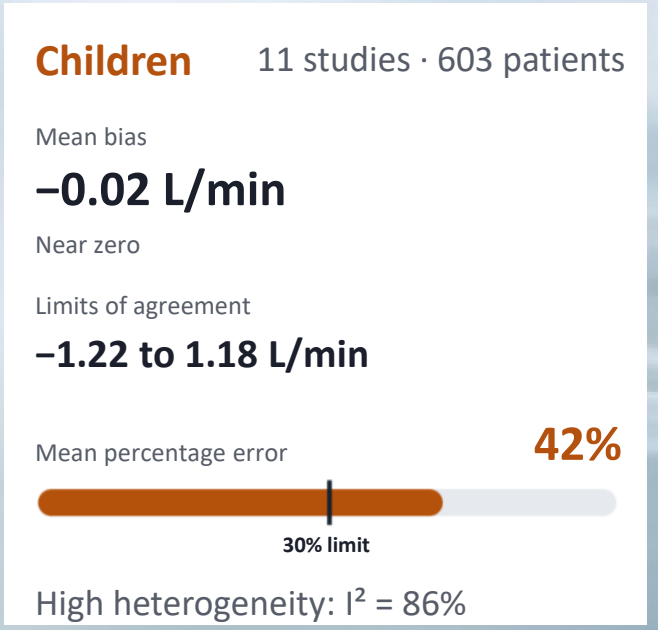


HR: 157 BP: 103/64 (77) PP: 39 HR: 133 BP: 98/63 (75) PP: 35

What is the gold standard?

- Adults
  - Pulmonary artery catheter
  - Transthoracic echocardiography
  - PiCCO2
- Pediatrics
  - Transthoracic echocardiography
  - PiCCO2
- Neonatology
  - Transthoracic echocardiography





"It does not replace thermodilution in adults or transthoracic echocardiography in children for measuring absolute cardiac output values"

Sanders M, et al. J Clin Monit Comput. 2020;34:433-460.

“It may be valid in children and adolescents.
In neonates, congenital heart disease and unstable patients,
the evidence is not yet sufficient”

Children and adolescents

13 studies with cardiac output in L/min

Median bias

–0.06 L/min

Near zero

Limits of agreement (median)

± 1.39 L/min

Median percentage error **31%**



Stroke volume: error 26% · I^2 = 31%

Neonates and infants

5 studies with cardiac output in L/min

Median bias

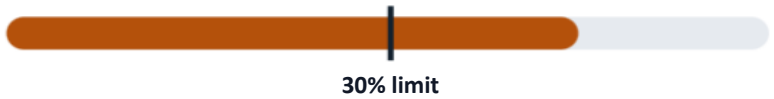
–0.01 L/min

Near zero

Limits of agreement (median)

± 0.35 L/min

Median percentage error **45%**

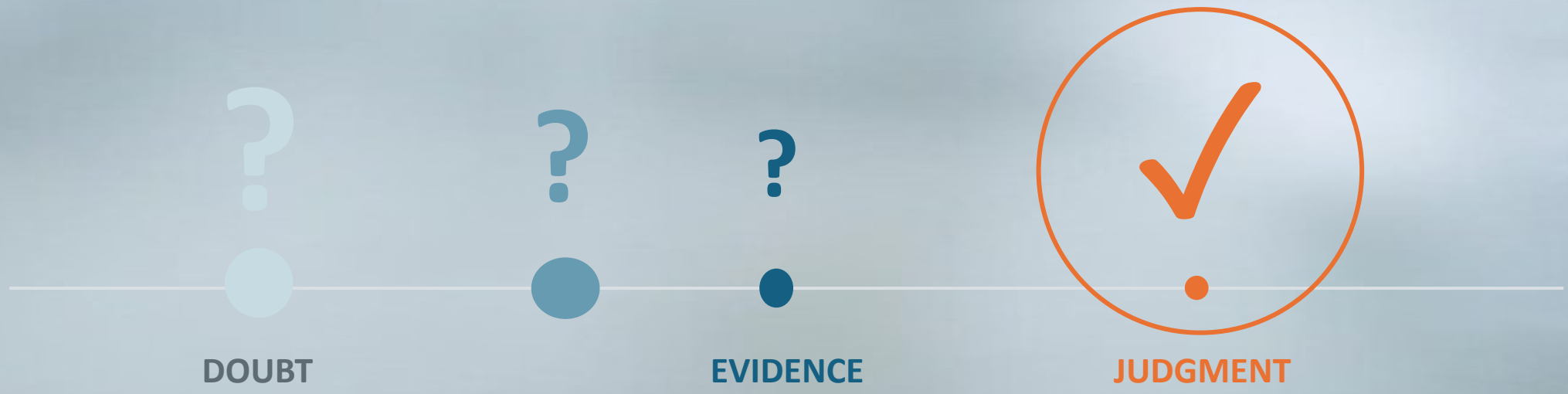


Stroke volume: error 45%, overestimated

Mansfield RC, et al. Crit Care Med. 2022;50(1):126-138.

Breaking down skepticism

Uncertainty shrinks when the question meets evidence and judgment.



Ask · Compare · Decide

Ranjit 2021 · 42 children, *1 mo–16 y, Chennai, 2018–20*

To assess how cardiac index and mean arterial pressure change after an early fluid bolus in pediatric septic shock, and whether that response relates to outcome

The bolus

10 mL/kg of lactated Ringer's over 30 minutes, within the first hour of shock

How it was measured

CI, SVI and SVRI by electrical cardiometry (ICON); invasive or non-invasive MAP

Responder

Increase ≥ 10% in CI or MAP, 10 minutes after the bolus

Hypothesis: the change in MAP after the bolus would predict the change in cardiac output.

Ranjit S, et al. Pediatr Crit Care Med 2021;22(8):e448–e458

Results (Ranjit 2021)

31%
had cardiac index rise ≥ 10% after the bolus (13/42)

38%
had MAP rise ≥ 10% after the bolus (16/42)

48%
improved neither cardiac index nor MAP (20/42)

27%
mortality when MAP did not rise (7/26), versus 0% when it rose

A rise in MAP after the bolus is a good sign.

There is no relationship between the change in MAP and in cardiac index ($r = 0.20$; $p = 0.196$)

Cardiac index fell ≥ 10% in **21%**

CONCLUSION

The response to a bolus is variable and unpredictable.
A rise in MAP does not guarantee a rise in output, and in some children the bolus lowers perfusion pressure.
Treat each bolus as a test; if MAP falls, consider vasoactive drugs before more fluids.

Ranjit S, et al. Pediatr Crit Care Med 2021;22(8):e448–e458

Rao 2021 · PICU *in Bangalore, June to November 2018*

To assess whether electrical cardiometry (ICON) can classify the hemodynamic profile and evaluate fluid responsiveness in pediatric septic shock

Patients

30 children aged 2 months to 16 years who remained in shock after a 20 mL/kg bolus

ICON categories

Vasoconstricted:
CI < 3.3 and SVRI > 1,600
Vasodilated:
CI > 5.5 and SVRI < 1,000

Responder

Increase ≥ 10% in CI with a second 20 mL/kg bolus

Also: compare the ICON classification with clinical cold or warm shock, and screen for myocardial dysfunction by echo within the first 6 hours.

Rao SS, et al. Indian J Crit Care Med 2021;25(2):185–192

Results (Rao 2021)

53.3%
vasodilated by ICON (16/30)

26%
of clinical cold shocks were vasodilated (5/19)

53.3%
responded to fluids: 10/14 vasoconstricted and 6/16 vasodilated

28.6%
mortality in non-responders (4/14), versus 0% in responders

Higher baseline SVV in responders (**24%** versus 18%)

TFC rose more in non-responders

Myocardial dysfunction in 5 children, all vasoconstricted, with **60%** mortality

CONCLUSION

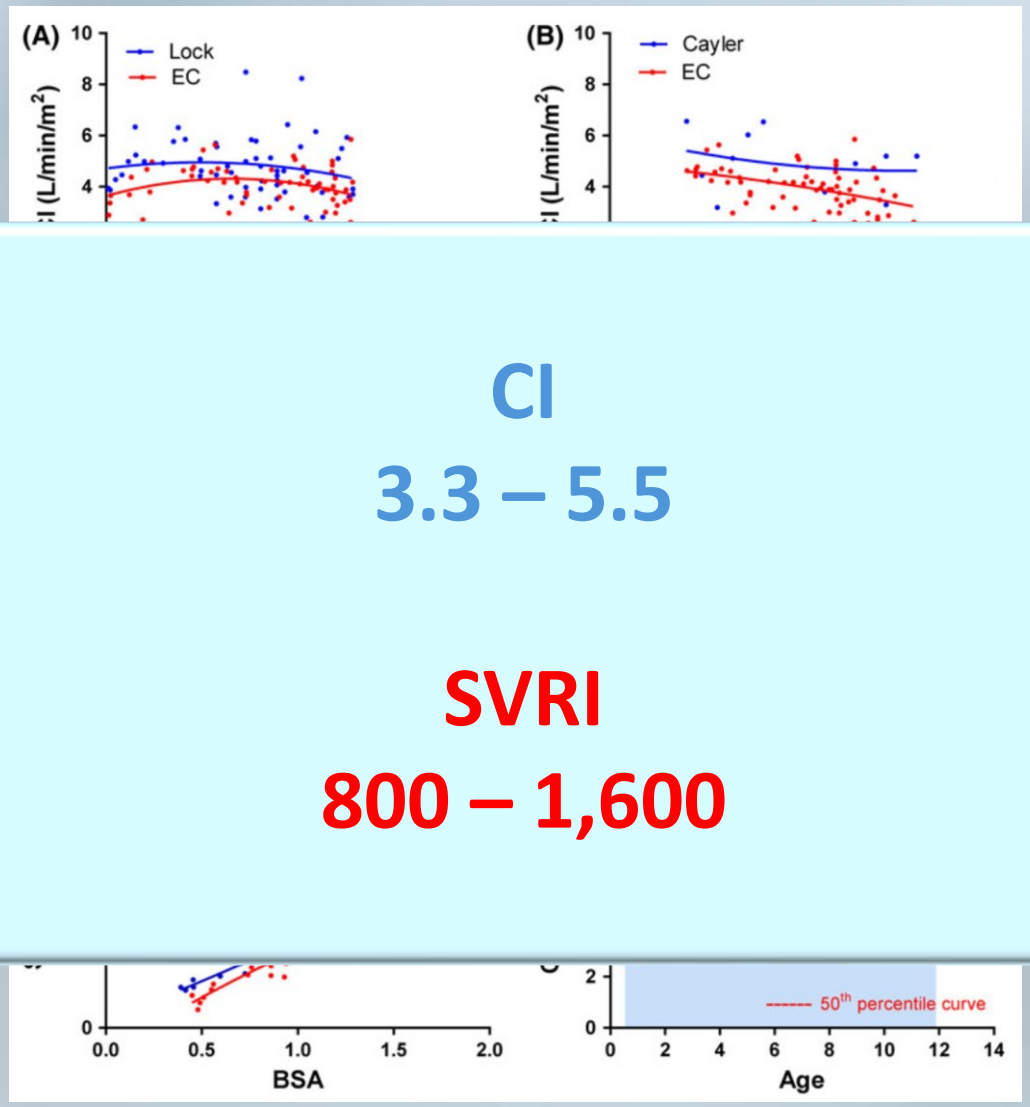
Electrical cardiometry classifies shock by CI and SVRI and measures fluid responsiveness at the bedside, continuously and non-invasively.
That classification guides treatment better than the cold versus warm shock distinction.

Rao SS, et al. Indian J Crit Care Med 2021;25(2):185–192

Are adult-derived CI and SVRI values the right target?



Boston Children's Hospital, 83 pre-discharge children



CI

3.3 – 5.5

SVRI

800 – 1,600

Age (years)	CI (L/min/m²)	SI (mL/m²/beat)	SVRI (dyn·s/cm⁵·m²)
1	3.8 [3.5 – 4.1]	29.4 [26.5 – 32.3]	1,352 [1,184 – 1,520]
2	3.9 [3.6 – 4.2]	32.5 [30.0 – 35.0]	1,315 [1,170 – 1,460]
3	4.0 [3.8 – 4.2]	35.3 [33.0 – 37.6]	1,287 [1,155 – 1,413]
4	4.1 [3.9 – 4.3]	37.8 [35.6 – 40.0]	1,267 [1,141 – 1,393]
5	4.2 [3.9 – 4.5]	40.0 [37.8 – 42.2]	1,256 [1,130 – 1,382]
6–8	4.3 [4.0 – 4.6]	42.0 – 44.9	1,254 – 1,277
9–10	4.3 [4.0 – 4.6]	45.9 – 46.6	1,302 – 1,335
11–12	4.2 [4.0 – 4.4]	47.1 – 47.2	1,378 – 1,429
13–14	4.1 – 4.0	47.0 – 46.6	1,490 – 1,559
15–16	3.8 – 3.7	45.8 – 44.8	1,637 – 1,724
17–18	3.5 – 3.3	43.4 – 41.8	1,820 – 1,924
19–20	3.1 – 2.9	39.8 – 37.6	2,038 – 2,160

Wong J, Agus MSD, Steil GM. *J Clin Monit Comput* 2013;27:81-91

Natraj 2022 · PICU *in Chennai, December 2018 to December 2020*

To describe tiered non-invasive monitoring to find the cause of persistent or recurrent shock and guide treatment

Patients

10 of 53 children aged 1 month to 16 years who remained in shock despite two 10 mL/kg boluses

Three tiers

T1: RV Doppler and diastolic function (**BESTFIT**)
T2: Cardiac output (**ICON**)
T3: Venous Doppler (**VExUS**)

Persistent shock

> 2 signs of hypoperfusion for 3 h despite treatment
Recurrent if it returns after ≥ 48 h of stability

BESTFIT: basic echocardiography to titrate fluids and inotropes in shock
Design: prospective observational study, pilot report. T1 and T2 take 5–7 minutes; T3, 4–5 minutes.

Natraj R, Ranjit S. Indian J Crit Care Med 2022;26(7):863–870

Results (Natraj 2022)

75%
came out of shock with first-BESTFIT therapy (40/53)

50%
of persistent or recurrent shocks had RV dysfunction (5/10)

50%
had diastolic dysfunction, often alongside systolic dysfunction (5/10)

80%
reversed shock after therapy was adjusted based on T1 + T2 + T3 (8/10)

Low SVRI in **4** children and high in 2
Venous congestion on VExUS in 3
2 of 10 died, both with persistent shock

CONCLUSION

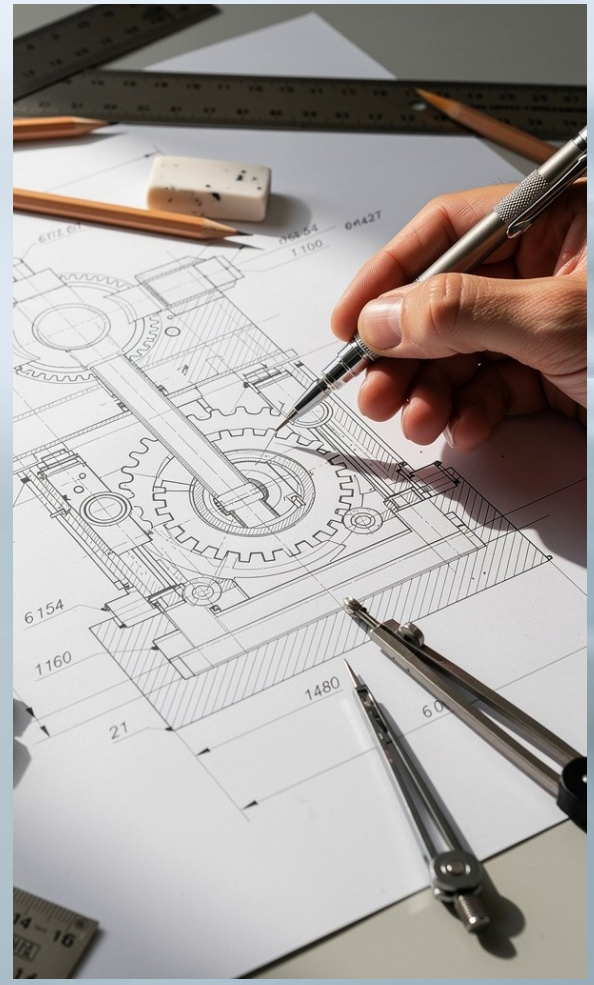
Persistent shock often combines several disorders that call for opposite treatments.
BESTFIT + T3 identifies them at the bedside without invasive procedures and allows fluids and vasoactives to be adjusted, which is useful where costly rescue therapies are not available.

Natraj R, Ranjit S. Indian J Crit Care Med 2022;26(7):863–870

Acute kidney injury

11-year-old boy, 84 kg, 160 cm

	Nitroprusside	Milrinone	Norepinephrine	Increase ultrafiltration	Extubation
HR	76	103	80	76	93
SBP	**152**	**164**	116	**139**	**149**
DBP	**102**	**78**	**56**	63	**85**
MAP	**119**	**99**	72	82	**104**
PP	**50**	**86**	**60**	**76**	**64**
SV	71	68	80	109	84
CO	5.4	7.0	6.4	8.3	7.8
SVV	13	22	3	10	5
TFC	**37**	**34**	27	**71**	**75**
ICON	**43.2**	**42.8**	50.4	88.8	65
SVR	**1,730**	855	**726**	839	883



In summary:

1. We have an FDA-approved device for all ages that calculates stroke volume continuously, non-invasively and with self-calibration.
2. Knowing SV, we can understand how the patient's cardiac output changes second by second.
3. Knowing CO, we can understand fluctuations in blood pressure through their close relationship with systemic vascular resistance.

In summary:

4. This information opens a window to precision medicine, because it shows whether macrohemodynamics and microhemodynamics are well coupled.
5. Discrepancies with standard methods for measuring cardiac output are just that: differences between methods that try to approximate a physiological value that varies second by second in a living, changing organism.

In summary:

6. A device that reads these variations and displays their trends improves the precision of monitoring.
7. Deciding with these data and trends has strengthened our residents' clinical reasoning, to the benefit of their patients.
8. Our responsibility is to generate knowledge and make use of the information this technology provides.

Future lines of study of clinical interest

- Standardization of values in healthy children.
- Relationship between thoracic fluid content and respiratory failure.
- Hemodynamic profile in non-septic critically ill patients: diabetic ketoacidosis, nephrotic syndrome, acute kidney injury, etc.
- Hemodynamic assessment before volume administration in the emergency department.

A WINDOW INTO

PRECISION HEMODYNAMICS

Optimizing clinical analysis in pediatric patients



OSYPKA MEDICAL

Thank you for your attention