

INTENZIVNÍ PÉČE V KARDIOLOGII – WORKSHOP ČAAK

30. KVĚTNA 2023 | PRAHA

ANALÝZA ARTERIÁLNÍ KŘIVKY

SIM/PL



Prof. MUDr. Jan Beneš, Ph.D.

KARIM LFP UK a FN Plzeň

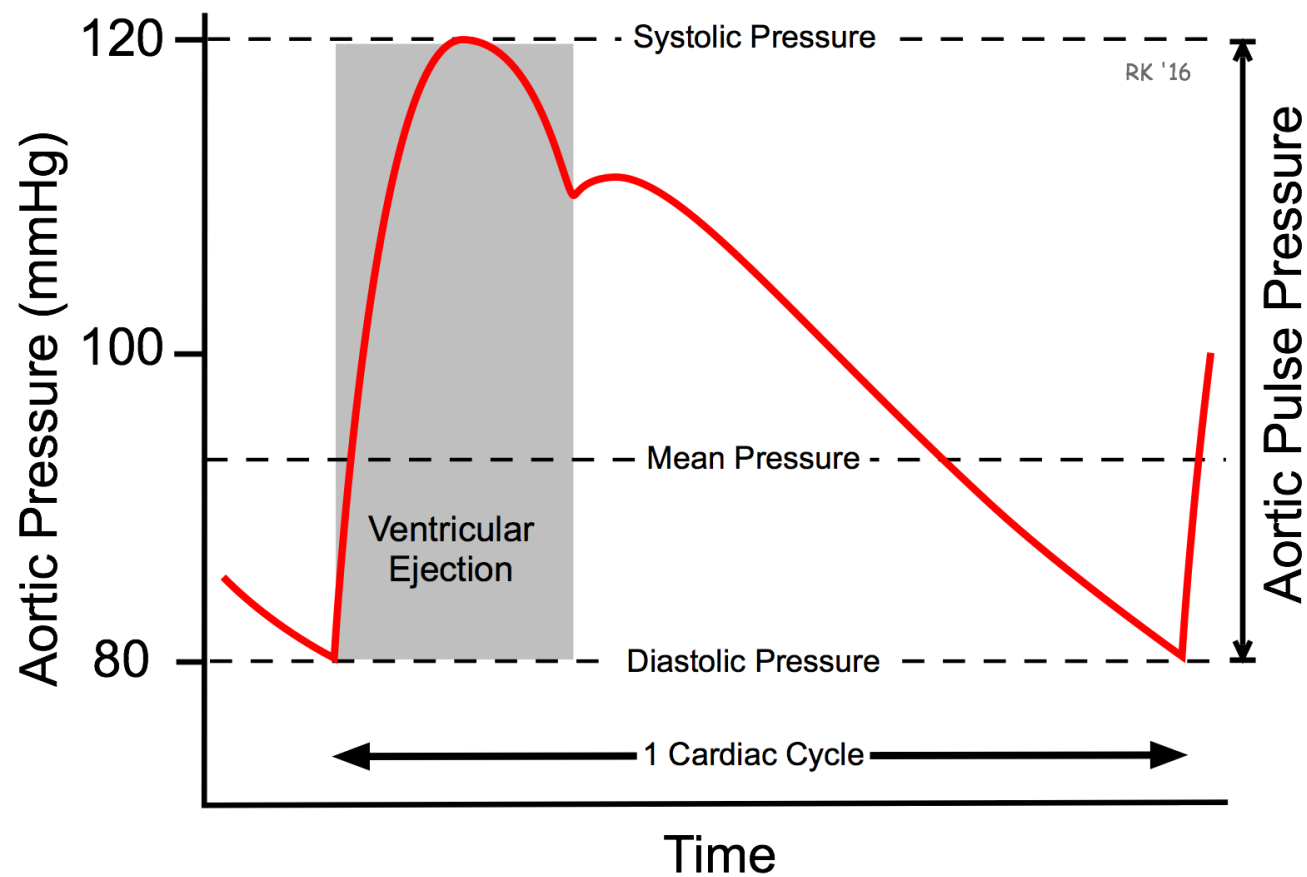
Biomedicínské a Simulační centrum LFP UK



O čem bychom si měli říct

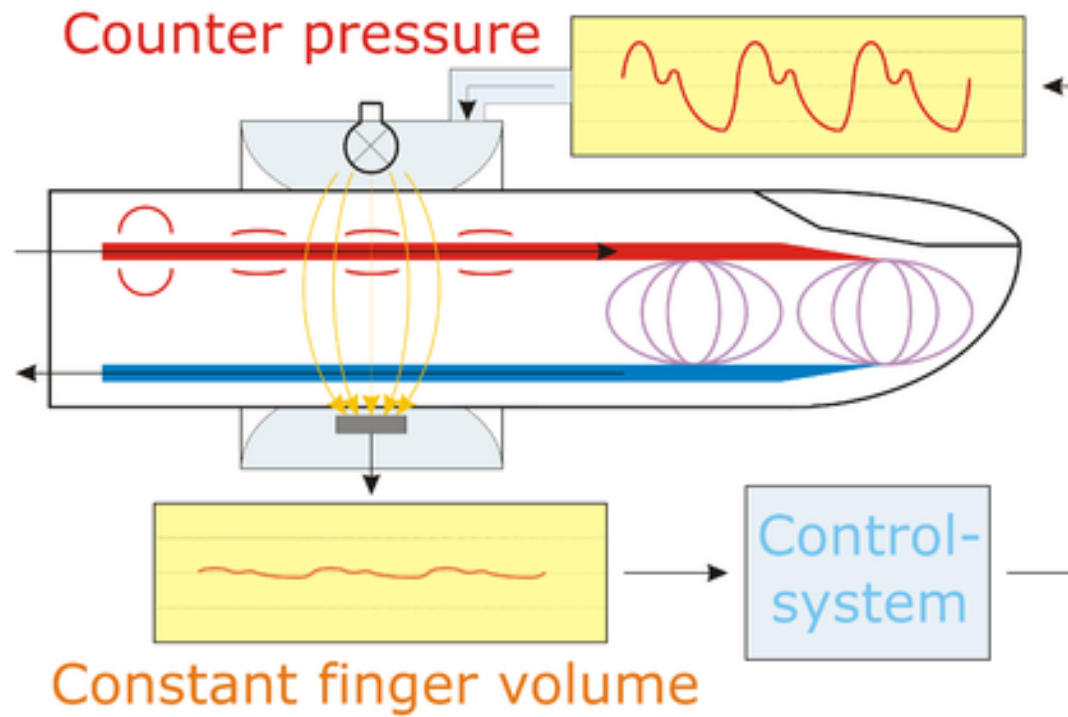
- Křivka arteriálního tlaku
- Převod z tlaku na objem
- Odvozené parametry

Křivka arteriálního tlaku – okometricky...



Zdroj křivky

VOLUME CLAMP / UNLOADING



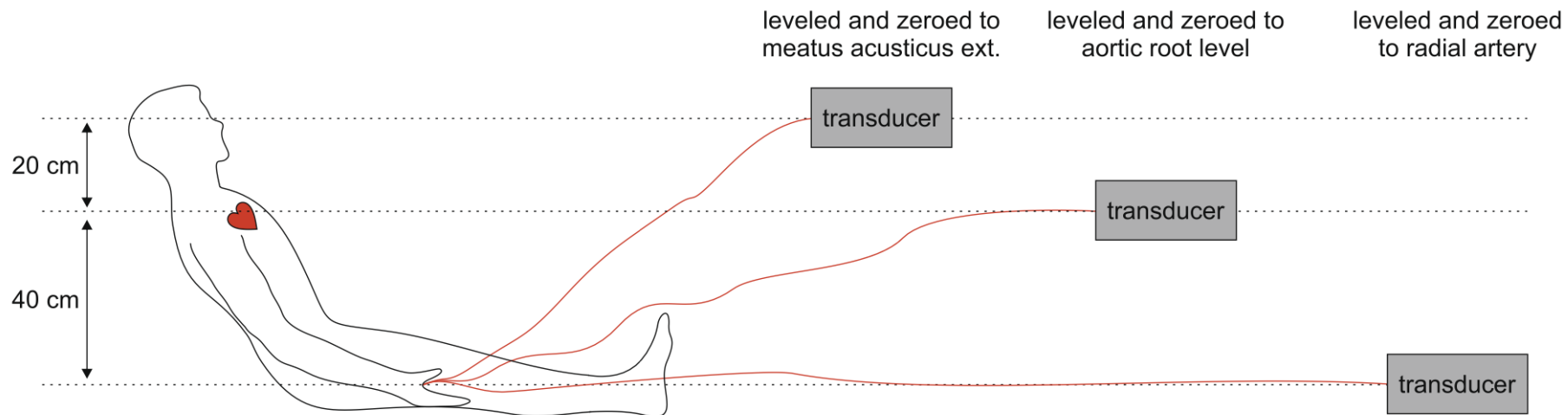
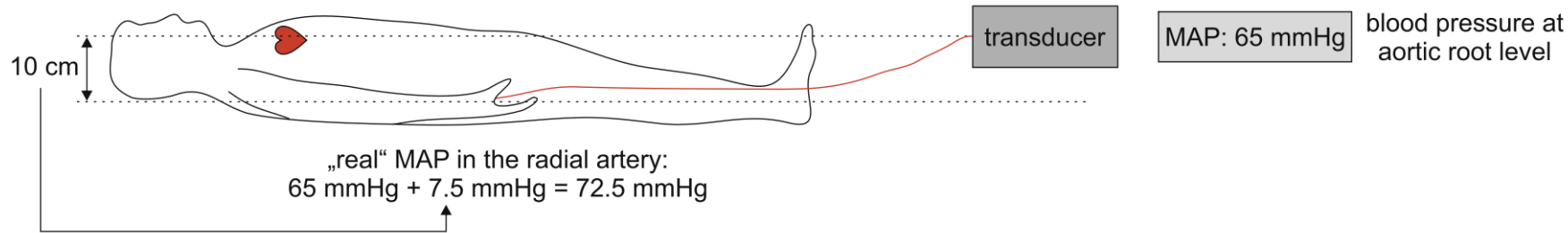
Prof. Jan PEŇÁZ

Zdroj křivky

VOLUME CLAMP / UNLOADING



Snímání křivky

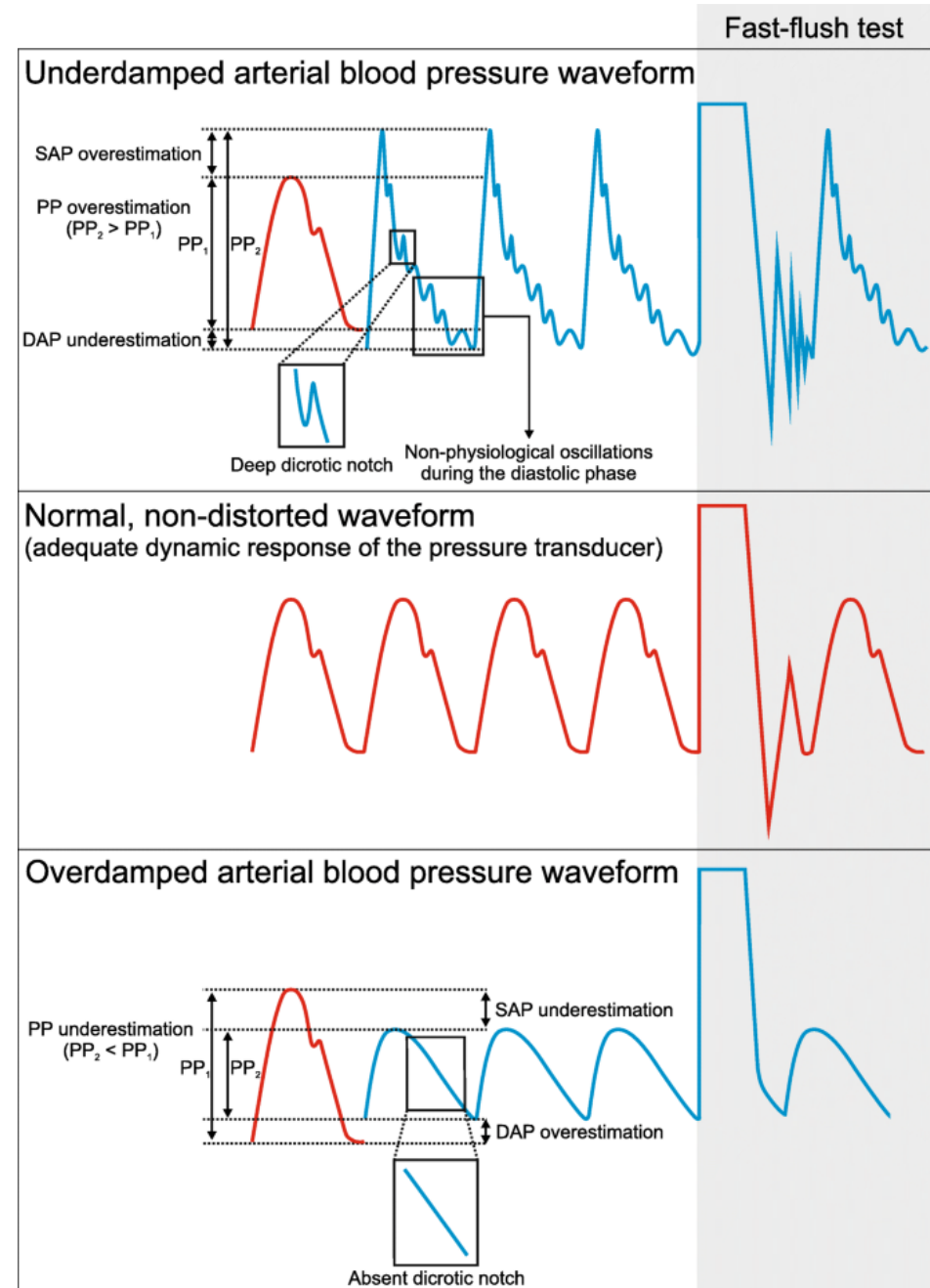


MAP displayed on monitor (mmHg):	MAP: 65	MAP: 65	MAP: 65
MAP in circle of Willis (mmHg):	MAP: 65	MAP: 50	MAP: 20
	😊	😐	😞

Snímání křivky

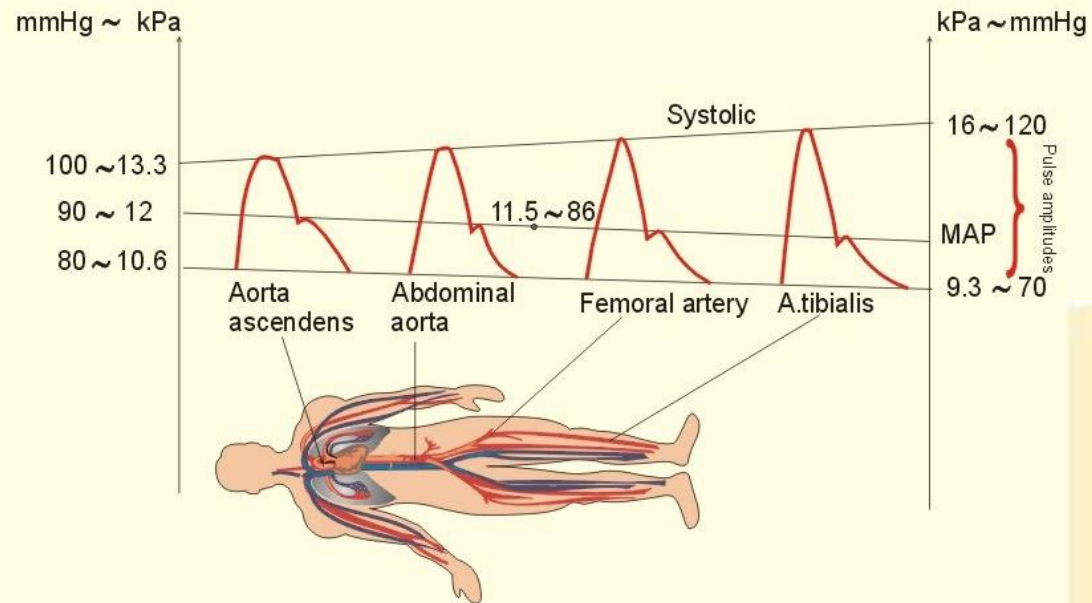
ŠPATNÉ NASTAVENÍ FILTRU
TUHÉ HADIČKY
VADNÝ PŘEVODNÍK

SNÍŽENÍ TLAKU V MANŽETĚ
VZDUCH V HADIČKÁCH
SRAŽENINY V HADIČKÁCH
PROBLÉM NA KANYLE
VOLNÁ SPOJENÍ

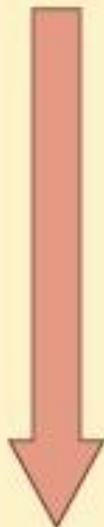


Tvar křivky

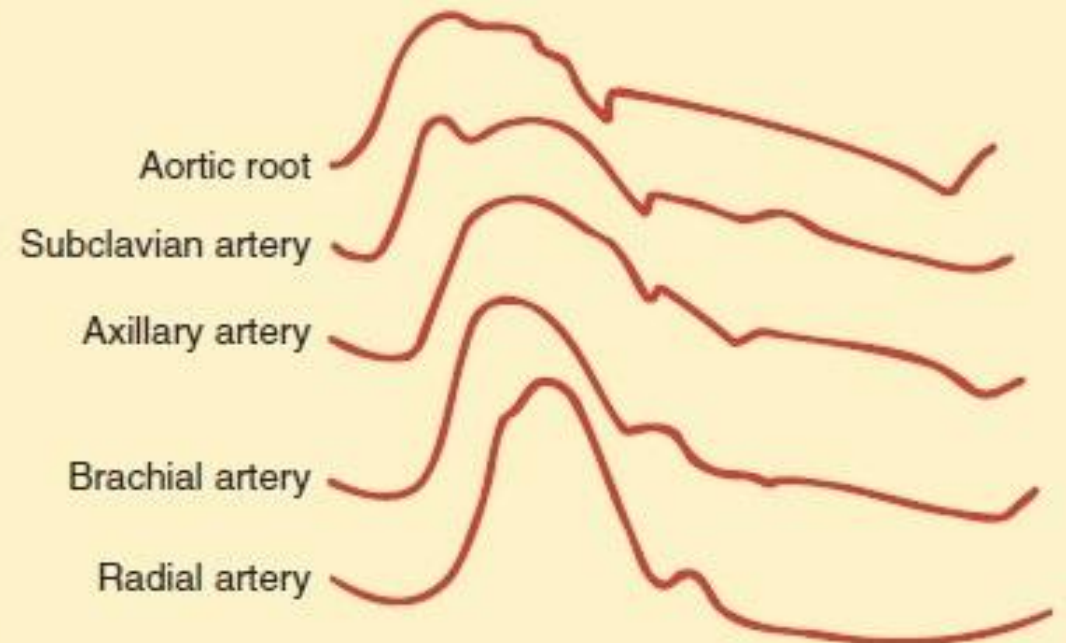
Changes In Arterial Pressures
In A Supine Person



Circulation
Central



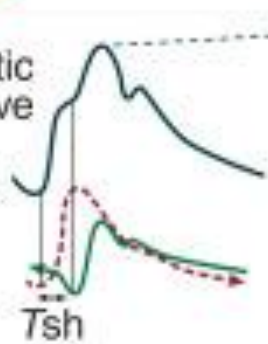
Peripheral



Tvar křivky

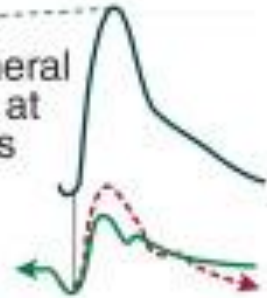


Recorded aortic pressure wave

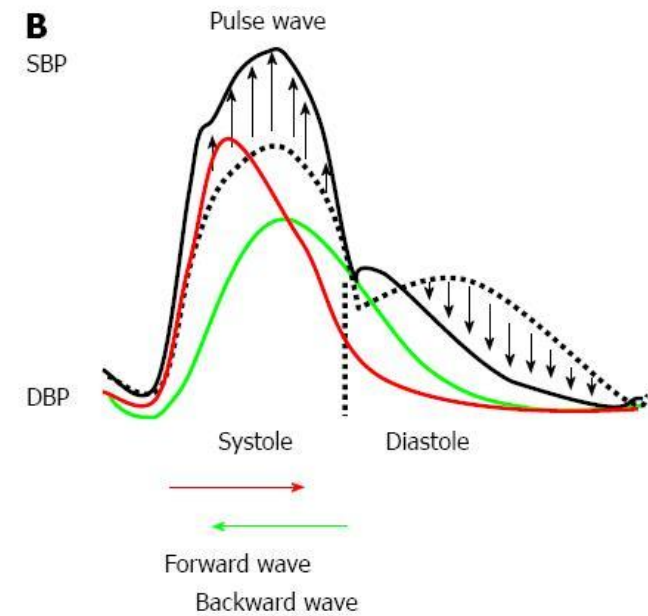
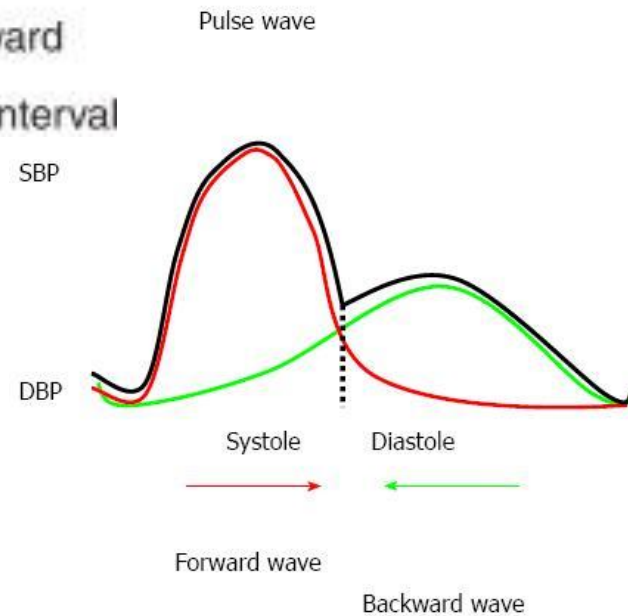


The time interval of pressure wave to and back from reflection sites

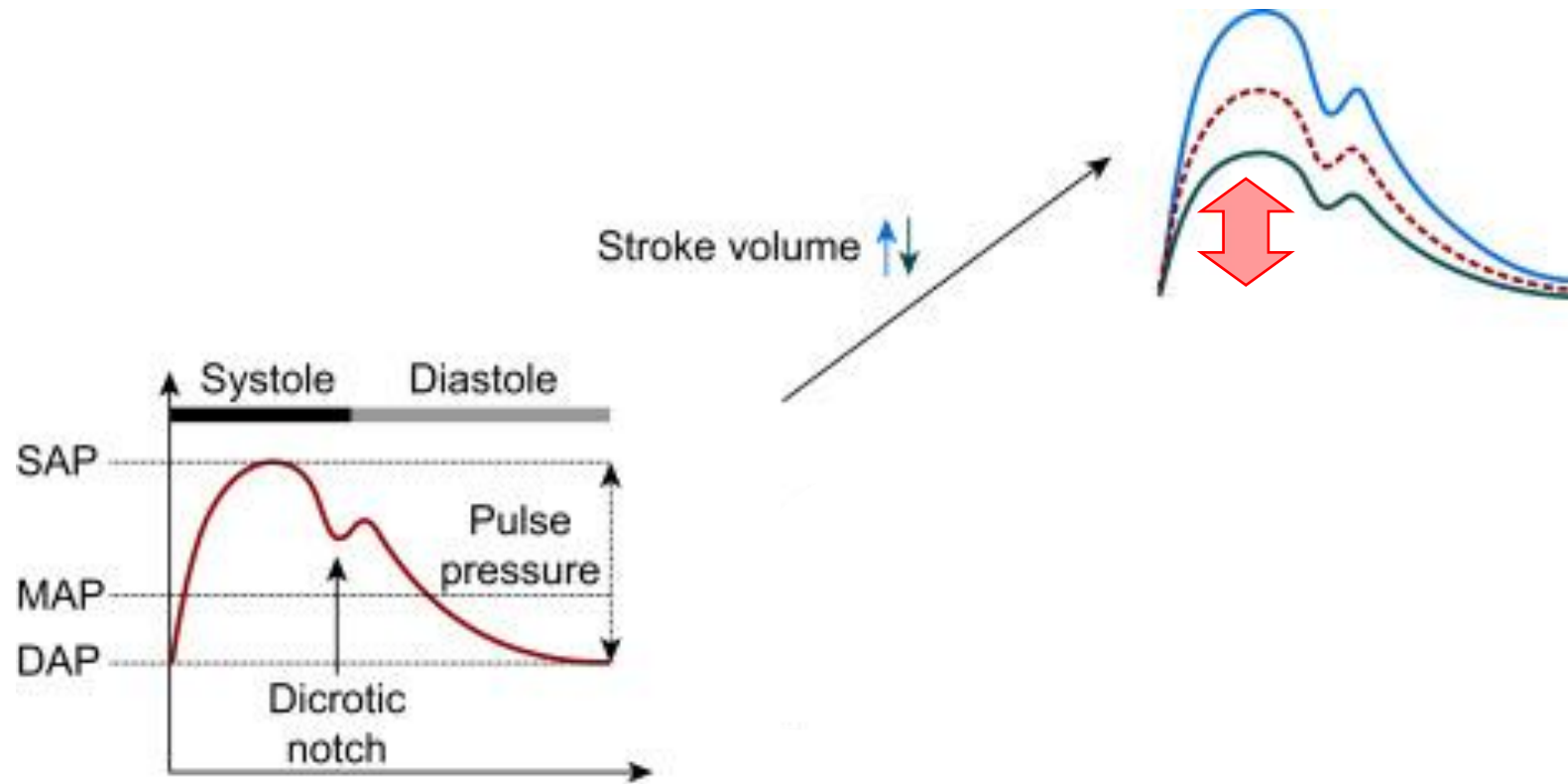
Recorded peripheral pressure wave at reflection sites



Forward and backward pressures are in phase: no time interval



Tvar křivky



NÍZKÝ PP
~ nízký tepový objem

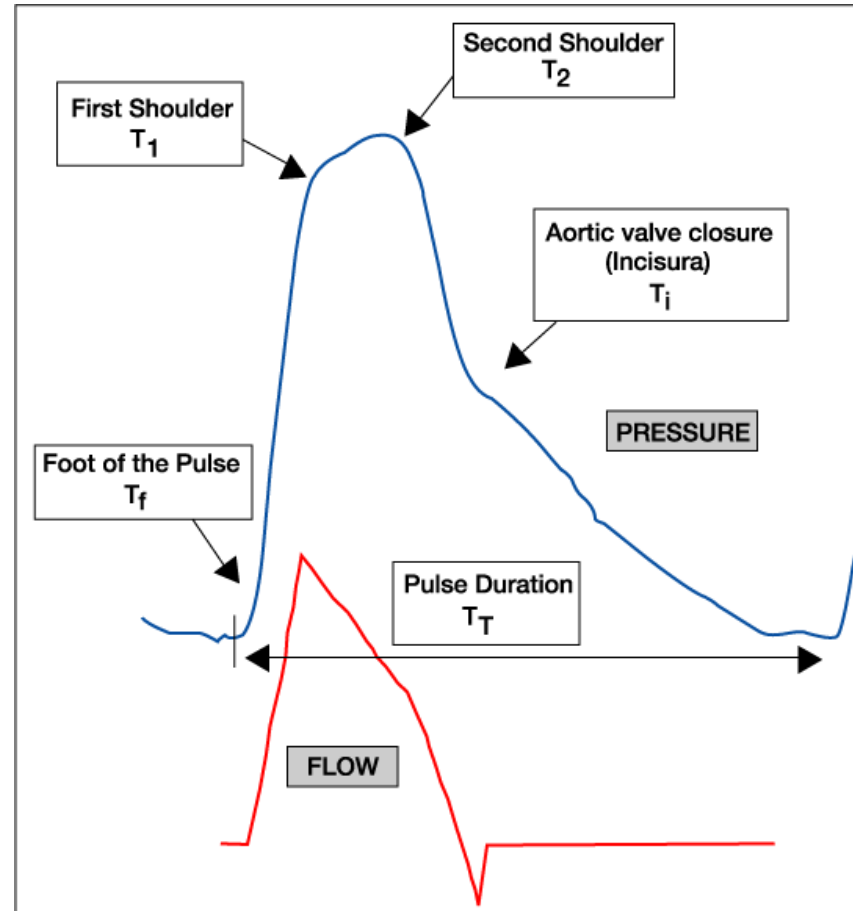
DAP < 40_{mmHg}
~ nízký tonus

Křivka arteriálního tlaku – okometricky...

- Invazivně vs. neinvazivně
- Fyzikální vliv
 - Místa nulování
 - Filtr tlumení křivky
- Pato/fyziologický vliv
 - Místa monitorace
 - Odražených vln
 - Poddajnosti aorty/velkých cév
 - Arteriálního tonu
 - Tepového objemu

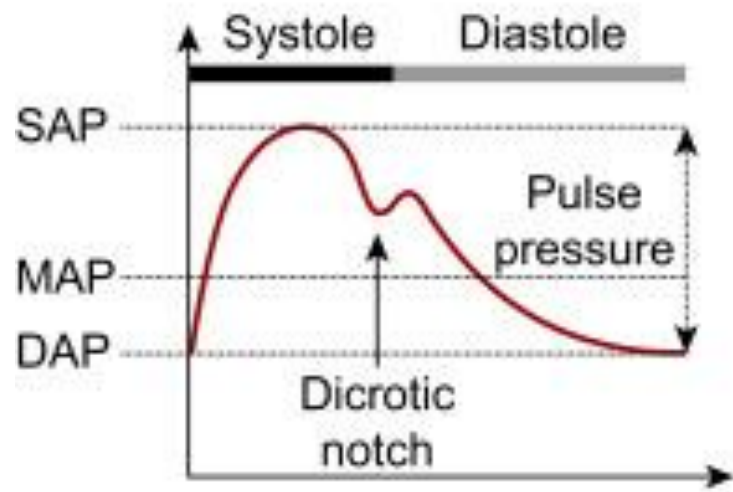


Převod z tlaku na průtok





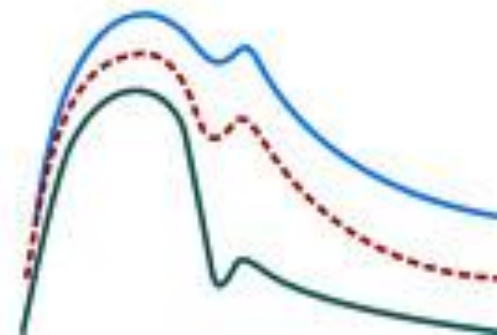
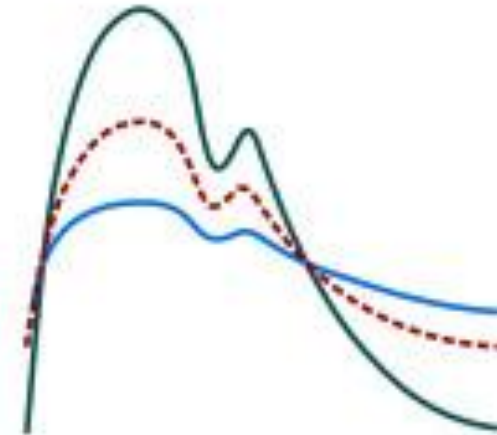
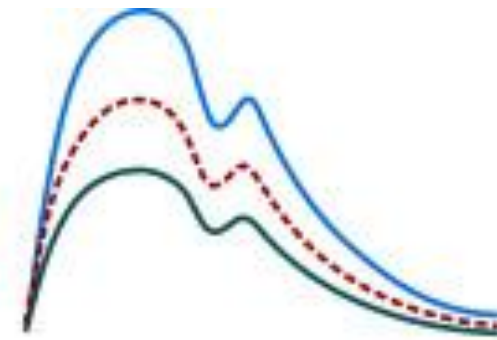
Continuous real-time beat-to-beat stroke volume / cardiac output

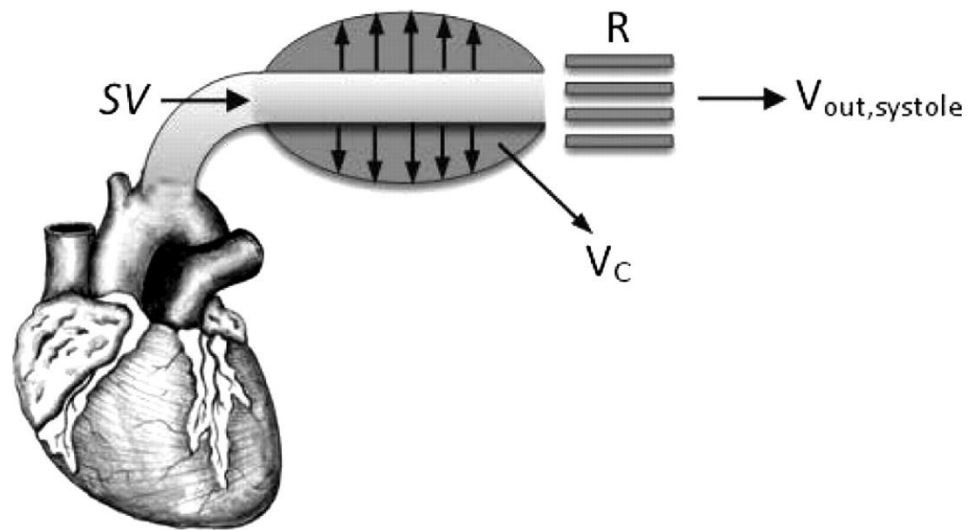
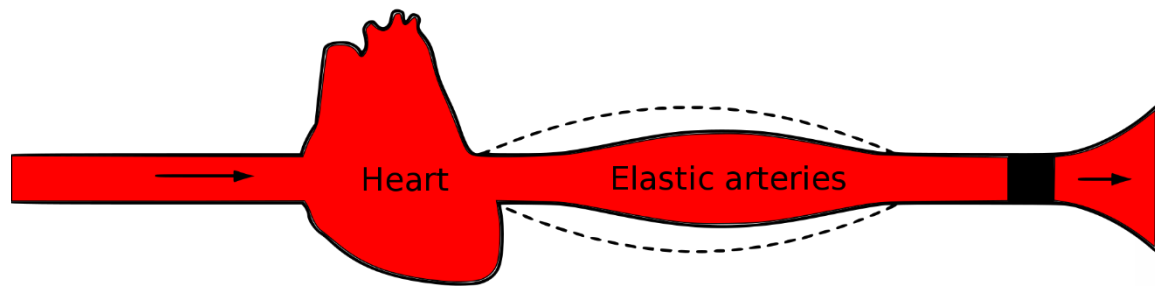
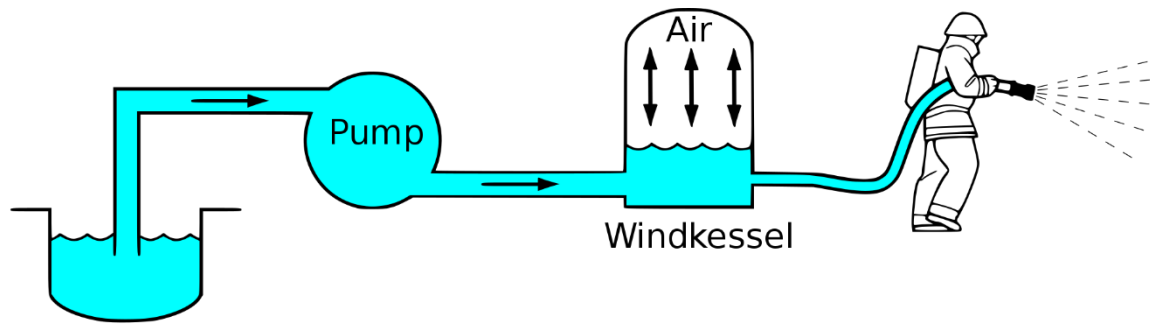


Stroke volume \updownarrow

Compliance \updownarrow

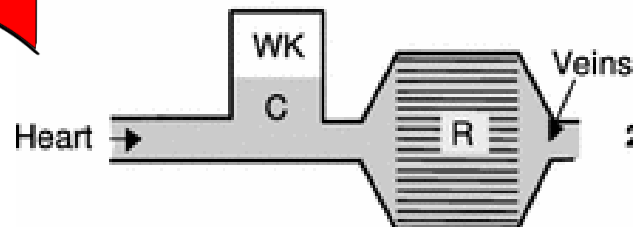
Systemic vascular resistance \updownarrow



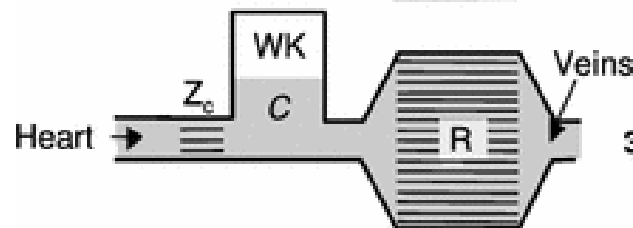
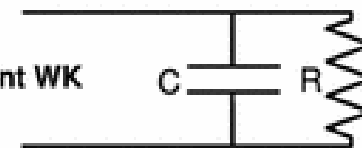


Hemodynamic Presentation

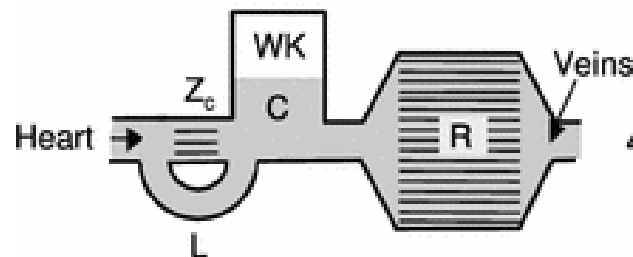
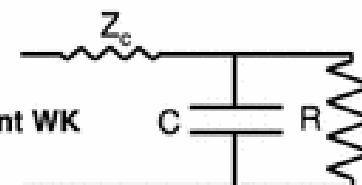
Electrical Presentation



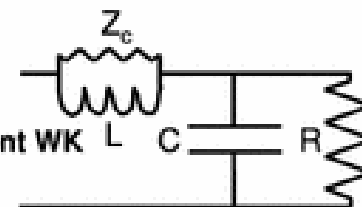
2-element WK



3-element WK

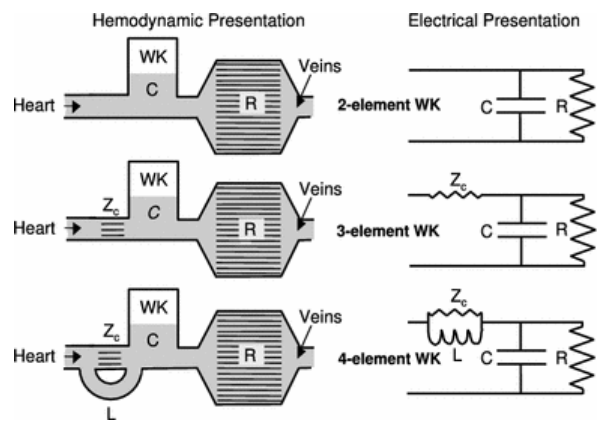


4-element WK



Cardiac output estimation using pulse wave analysis—physiology, algorithms, and technologies: a narrative review

Bernd Saugel^{1,2,*†}, Karim Kouz^{1,†}, Thomas W. L. Scheeren³, Gillis Greiwe¹, Phillip Hoppe¹, Stefano Romagnoli^{4,5} and Daniel de Backer⁶



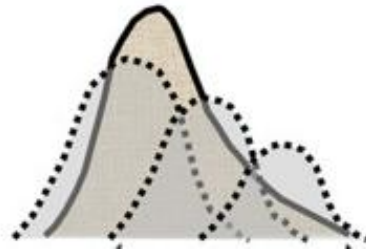
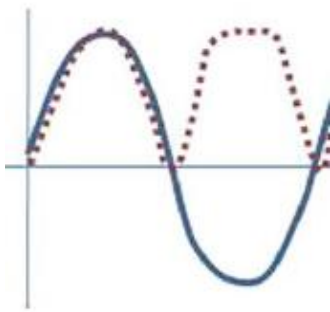
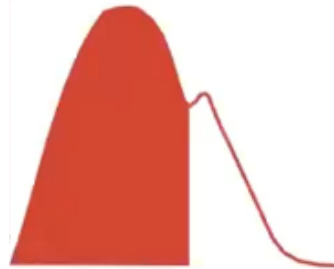
= Modelflow algoritmus

Windkessel model

Analýza dlouhých intervalů = statistická rekonstrukce ideální křivky

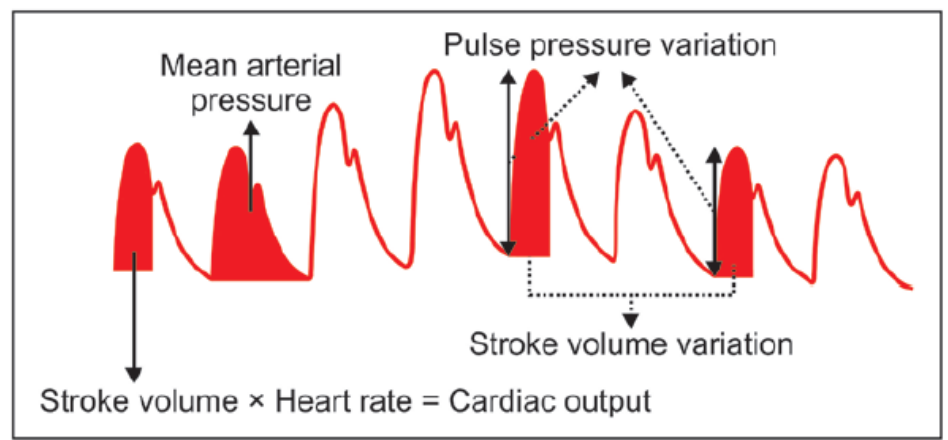
Pulse power analýza = převod tlaku na sílu

Pressure Recording Analytical Method = odstranění interferencí

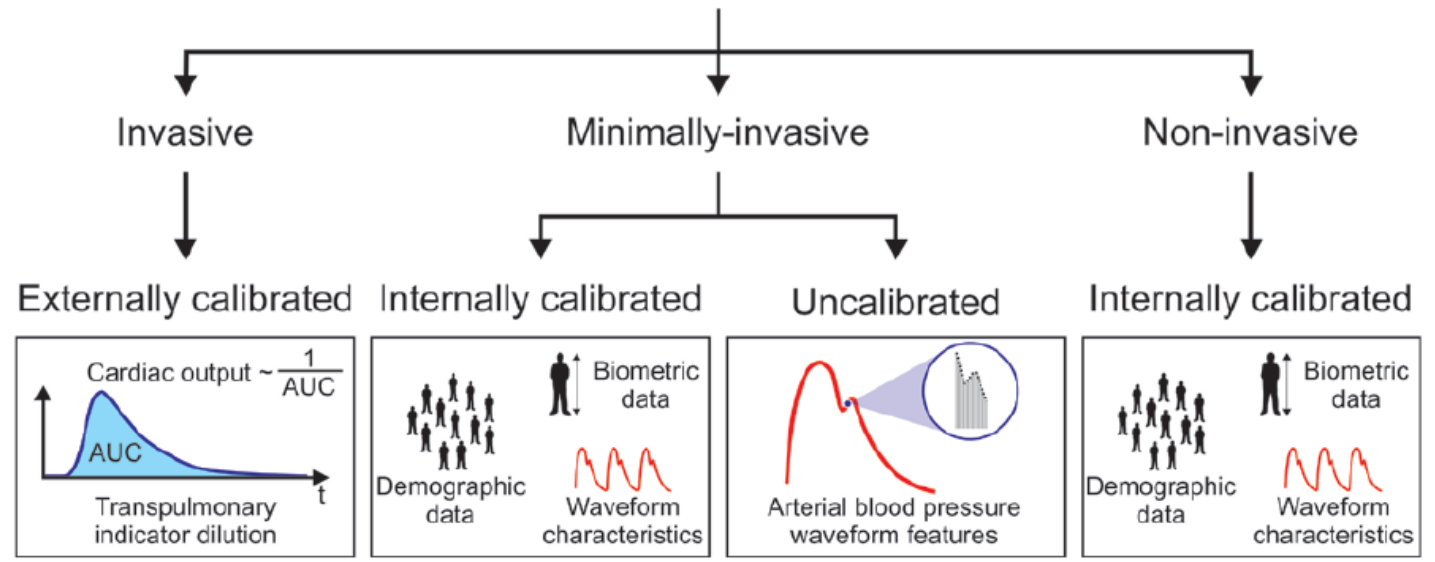


Pulse Wave Analysis to Estimate Cardiac Output

Karim Kouz, M.D., Thomas W. L. Scheeren, M.D., Daniel de Backer, M.D., Bernd Saugel, M.D.



Pulse wave analysis



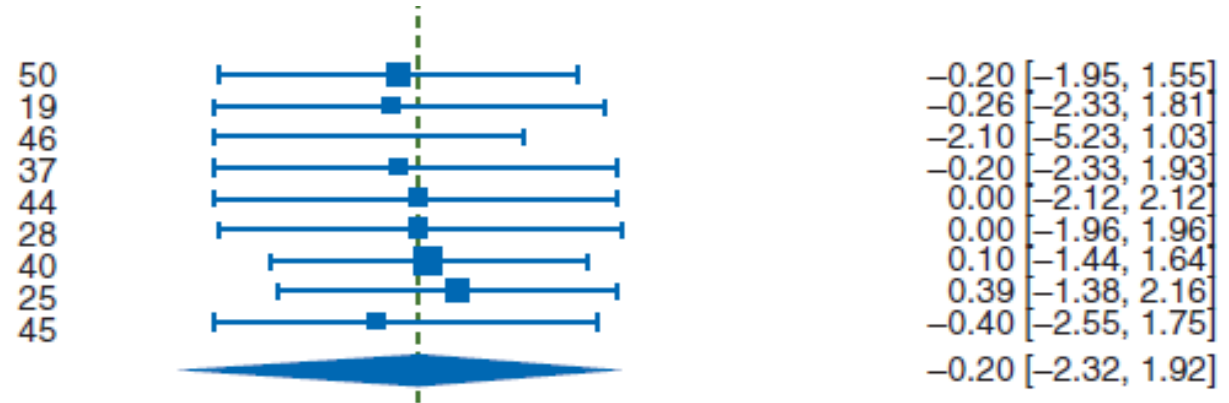
Accuracy and precision of non-invasive cardiac output monitoring devices in perioperative medicine: a systematic review and meta-analysis[†]

A. Joosten^{1,*}, O. Desebbe², K. Suehiro³, L. S.-L. Murphy⁴, M. Essiet⁵,
B. Alexander⁶, M.-O. Fischer^{7,8}, L. Barvais¹, L. Van Obbergh¹,
D. Maucort-Boulch⁹ and M. Cannesson¹⁰

niPCA

Wagner (2015)
Hofhuizen (2014)
Gerhardt (2000)
Fischer (2013)
Fischer (2012)
Bubeneck-Turconi (2013)
Broch (2012)
Bogert (2010)
Ameloot (2014)

Heterogeneity: $Q=46.0$ ($P<0.001$), $I^2=82.6\%$



REVIEW ARTICLES

Systematic review of uncalibrated arterial pressure waveform analysis to determine cardiac output and stroke volume variation

C. Slagt^{1*}, I. Malagon² and A. B. J. Groeneveld³



Weighted average for third generation

Patients	5.7	-0.50	0.77	28
95% confidence interval	5.4–6.0	-0.59 to -0.41	0.70–0.83	25–31
Data	5.6	-0.46	0.81	30
95% confidence interval	5.4–5.7	-0.50 to -0.42	0.78–0.83	29–32



Weighted average for third generation

Patients	4.7	-0.02	0.58	25
95% confidence interval	4.6–4.8	-0.02 to -0.01	0.57–0.59	24–26
Data	4.7	-0.01	0.58	25
95% confidence interval	4.7–4.7	-0.01 to -0.01	0.58–0.59	25–25

Weighted average for third generation

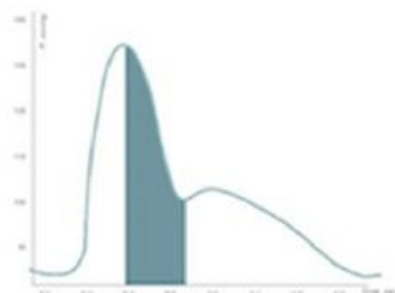
Patients	6.4	-0.12	1.71	51
95% confidence interval	6.3–6.5	-0.22 to 0.02	1.65–1.77	49–53
Data	6.5	-0.70	2.19	66
95% confidence interval	6.5–6.5	-0.71 to -0.68	2.18–2.21	66–67



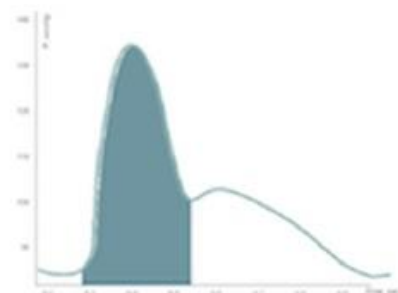
Převod z tlaku na průtok...

- Vyžaduje maximálně „opečovanou“ křivku
- Kalibrované a nekalibrované
- Čtyři modely nekalibrovaných
 - Windkessel
 - Pulse power analýza
 - Analýza dlouhých intervalů/statistická rekonstrukce
 - Pressure recording analytical method
- Přesnost klesá s množstvím vlivů na křivku

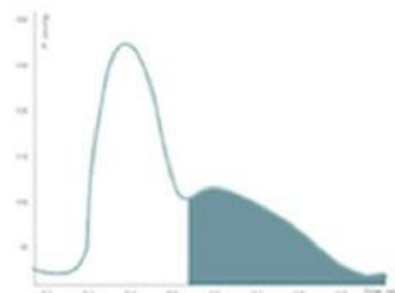
Odvozené parametry



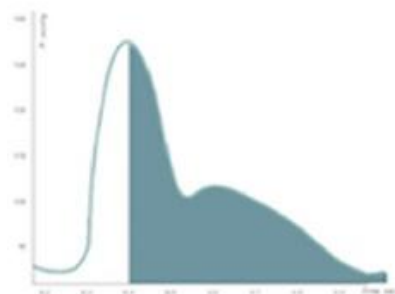
Aortic compliance



Stroke volume



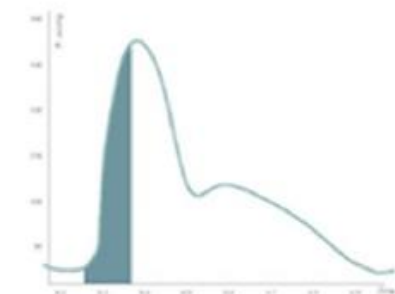
Vascular tone



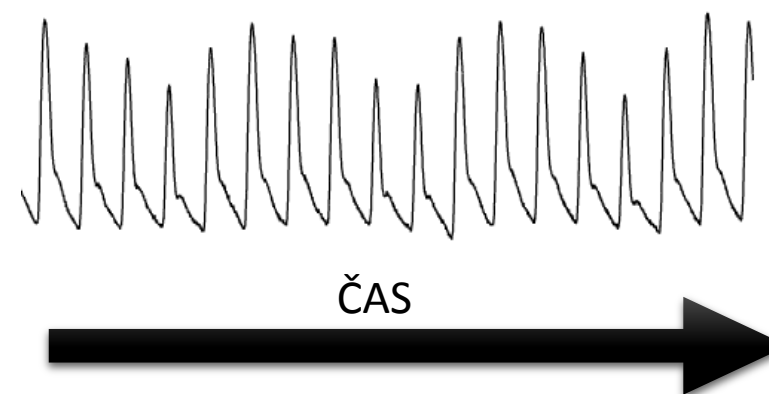
Afterload



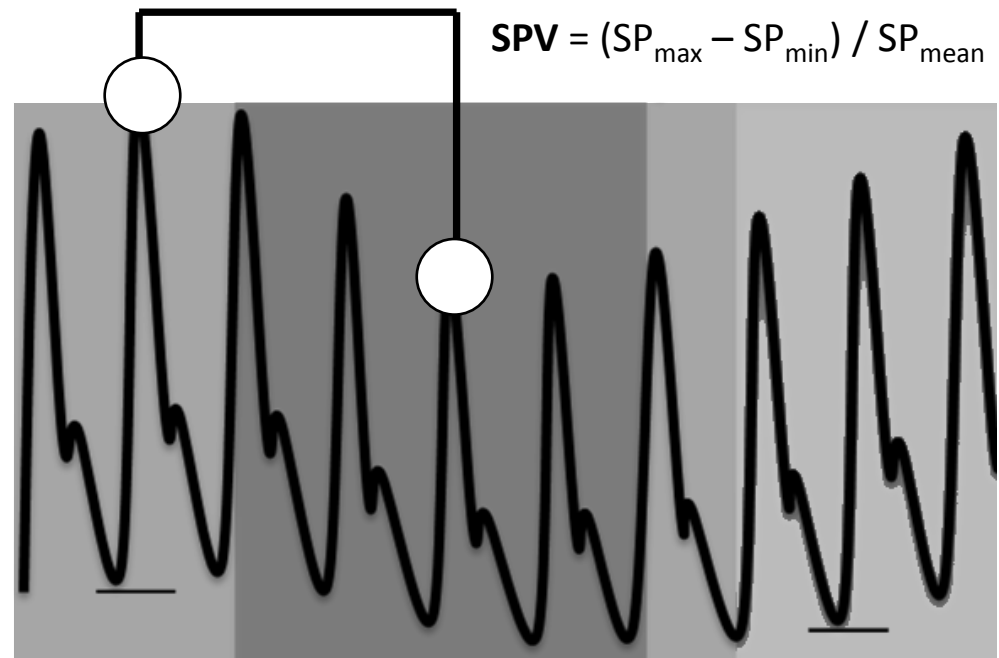
Full cardiac cycle



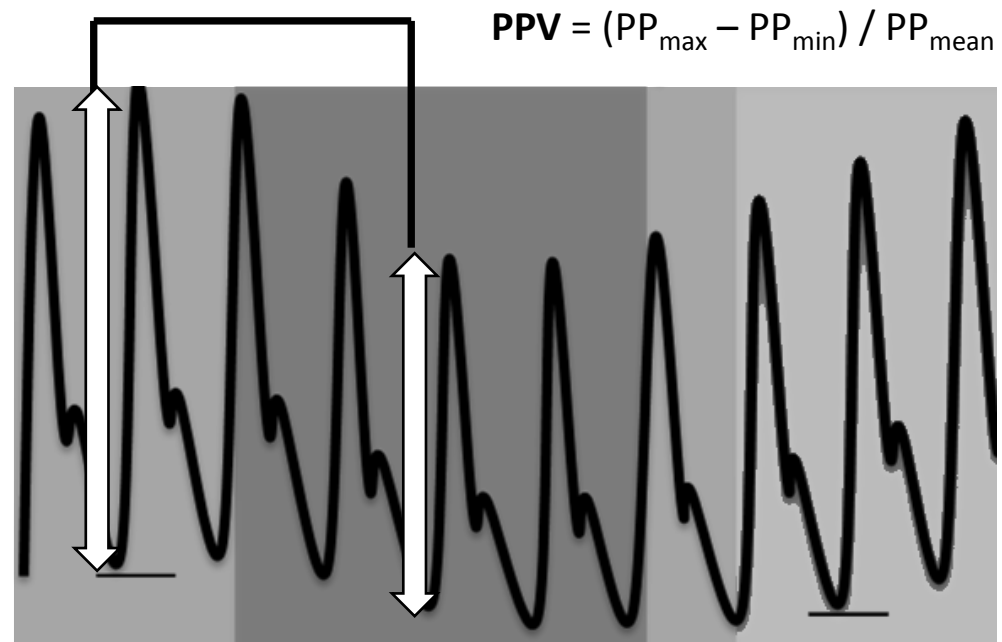
Contractility



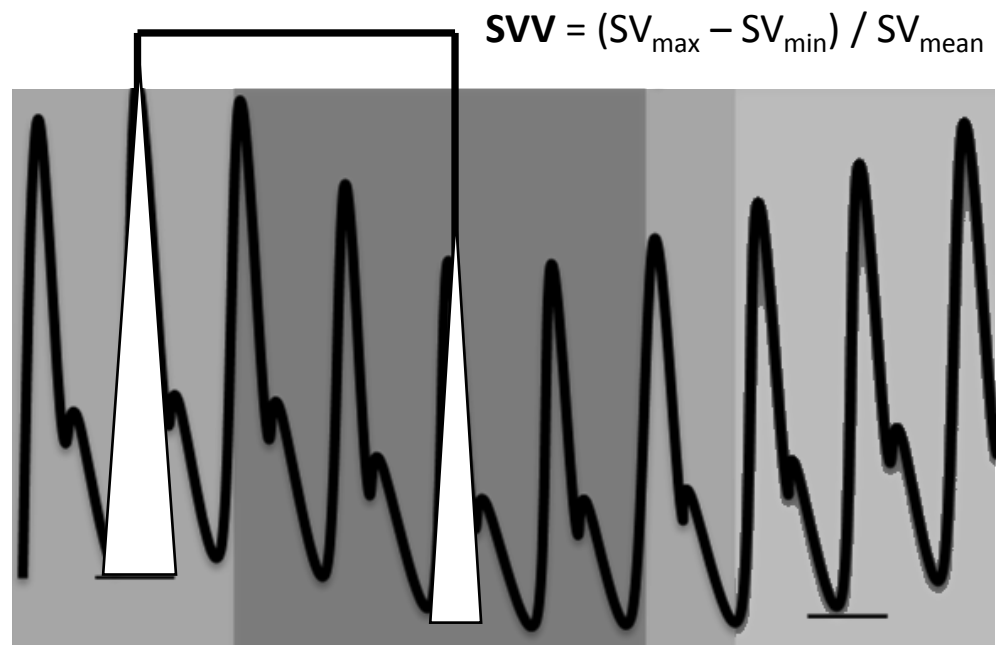
ŽILNÍ NÁVRAT
=
PRELOAD



ŽILNÍ NÁVRAT
=
PRELOAD



ŽILNÍ NÁVRAT
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PRELOAD



REVIEW

Open Access

Hemodynamic parameters to guide fluid therapy

Paul E Marik^{1*}, Xavier Monnet², Jean-Louis Teboul²

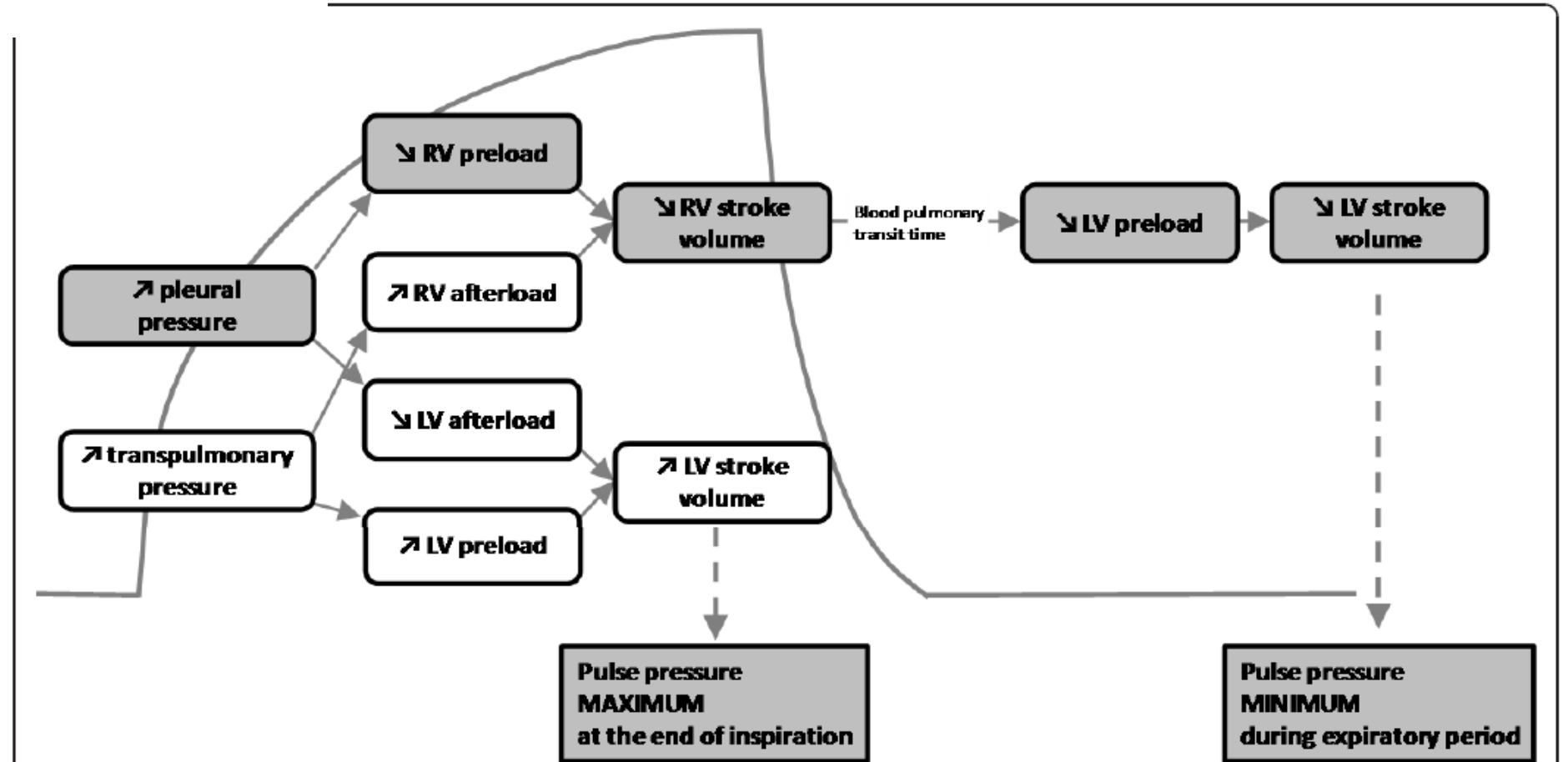
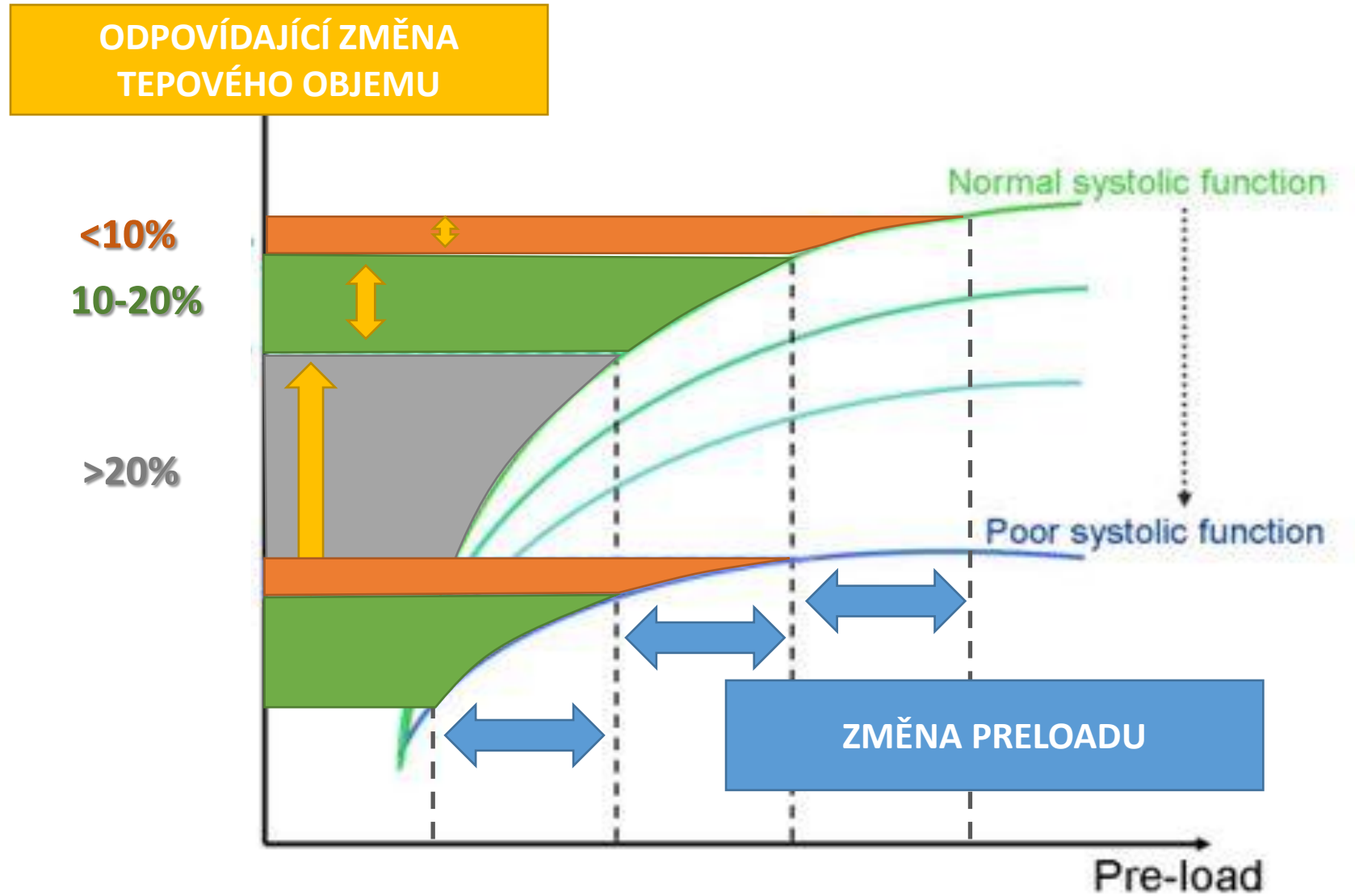


Figure 2 Heart-lung interactions. Hemodynamic effects of mechanical ventilation. The cyclic changes in left ventricular (LV) stroke volume are mainly related to the expiratory decrease in LV preload due to the inspiratory decrease in right ventricular (RV) filling. Reproduced with permission from Critical Care/Current Science Ltd [24].

FUNKČNÍ TESTY – FRANK STARLINGOVA KŘIVKA



SVV



Variace tlaku
SPV
PPV
dDown

Variace Dopplerova signálu
 Δ ABF
VTI

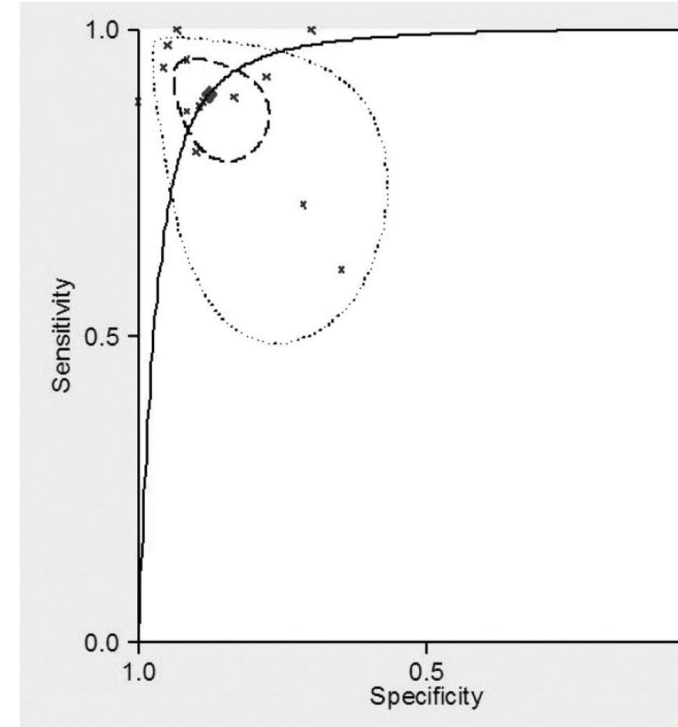
Plethysmografické variace
PVI
 Δ POP

Zkratka	Název	Zóna cut off	Automatické hodnocení
SVV	Variace tepového objemu	9-12%	Nutné
PPV	Variace pulzního tlaku	9-13%	Možné
SPV	Variace systolického tlaku	10-13%	Ne
Δ Down	Pokles STK oproti end-expiriu	5 mmHg	Ne
PVI	Variace pletysmografického signálu	9,5-15%	Možné
----	variace VTI/ABF		Ne

Dynamic changes in arterial waveform derived variables and fluid responsiveness in mechanically ventilated patients: A systematic review of the literature*

Paul E. Marik, MD, FCCM; Rodrigo Cavallazzi, MD; Tajender Vasu, MD; Amyr Hirani, MD

29 studies = 685 patients
 AUC (PPV) = 0,94 (0,92-0,96) ...12,5%
 AUC (SVV) = 0,84 (0,81-0,87) ... 11,6%



J Anesth (2011) 25:904-916
 DOI 10.1007/s00540-011-1217-1

REVIEW ARTICLE

Accuracy of stroke volume variation in predicting fluid responsiveness: a systematic review and meta-analysis

Zhongheng Zhang · Baolong Lu ·
 Xiaoyan Sheng · Ni Jin

23 studies – 568 patients
 AUC (all) = 0,93 (0,91-0,95)

Setting [no. of studies (data sets)]	Sensitivity (95% CI)	Specificity (95% CI)	DOR (95% CI)	AUC-ROC (95% CI) ^a
Across all settings (12 [15])	0.81 (0.77–0.85)	0.80 (0.70–0.88)	18.4 (9.52–35.5)	0.93 (0.907–0.945)
In OR under general anesthesia (8 [10])	0.80 (0.75–0.84)	0.78 (0.61–0.89)	14.1 (5.84–34.3)	0.94 (0.92–0.96)
In ICU (4 [5])	0.86 (0.78–0.92)	0.84 (0.74–0.91)	28.3 (12.3–65.1)	0.85 (0.79–0.91)
Patients ventilated with TV > 8 ml/kg (10 [13])	0.81 (0.77–0.85)	0.80 (0.68–0.89)	17.5 (8.44–36.5)	0.85 (0.82–0.88)
Hemodynamic monitoring with PiCCO system (6 [6])	0.80 (0.72–0.85)	0.84 (0.75–0.91)	21.0 (10.7–41.5)	0.85 (0.81–0.89)
Hemodynamic monitoring with Vigileo system (7 [9])	0.85 (0.78–0.90)	0.78 (0.58–0.91)	20.8 (6.09–71.2)	0.96 (0.94–0.98)

- L** Low HR/RR ratio
(Extreme bradycardia or high frequency ventilation)
- I** Irregular heart beats
- M** Mechanical ventilation with low tidal volume
- I** Increased abdominal Pressure (Pneumoperitoneum)
- T** Thorax open
- S** Spontaneous breathing

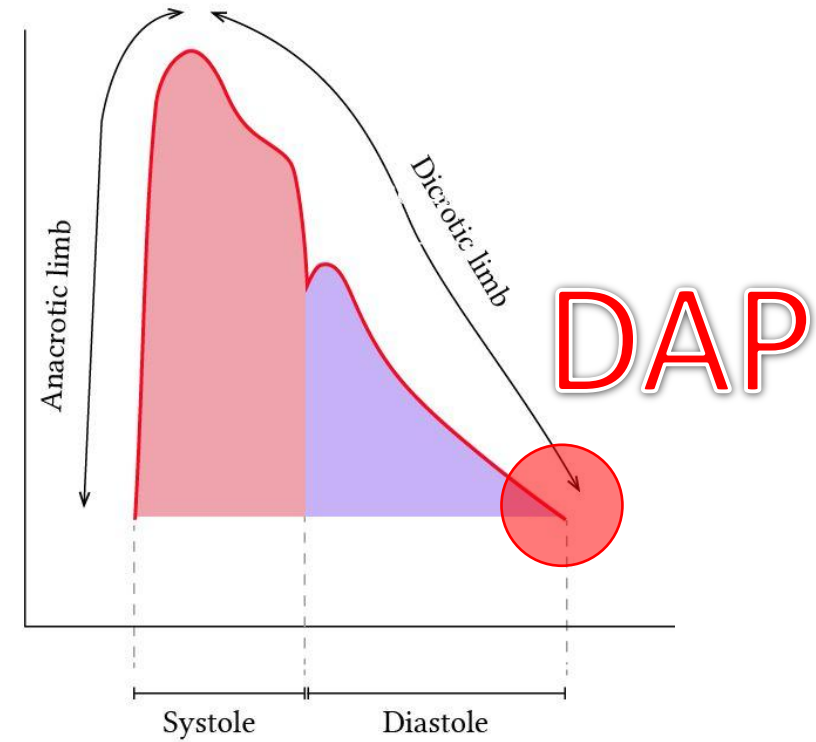
False positive	False negative
	✓
✓	
	✓
✓	
	✓
✓	✓

RESISTANCE
/ELASTANCE
=
AFTERLOAD

SHUNTING

VENOUS TONE

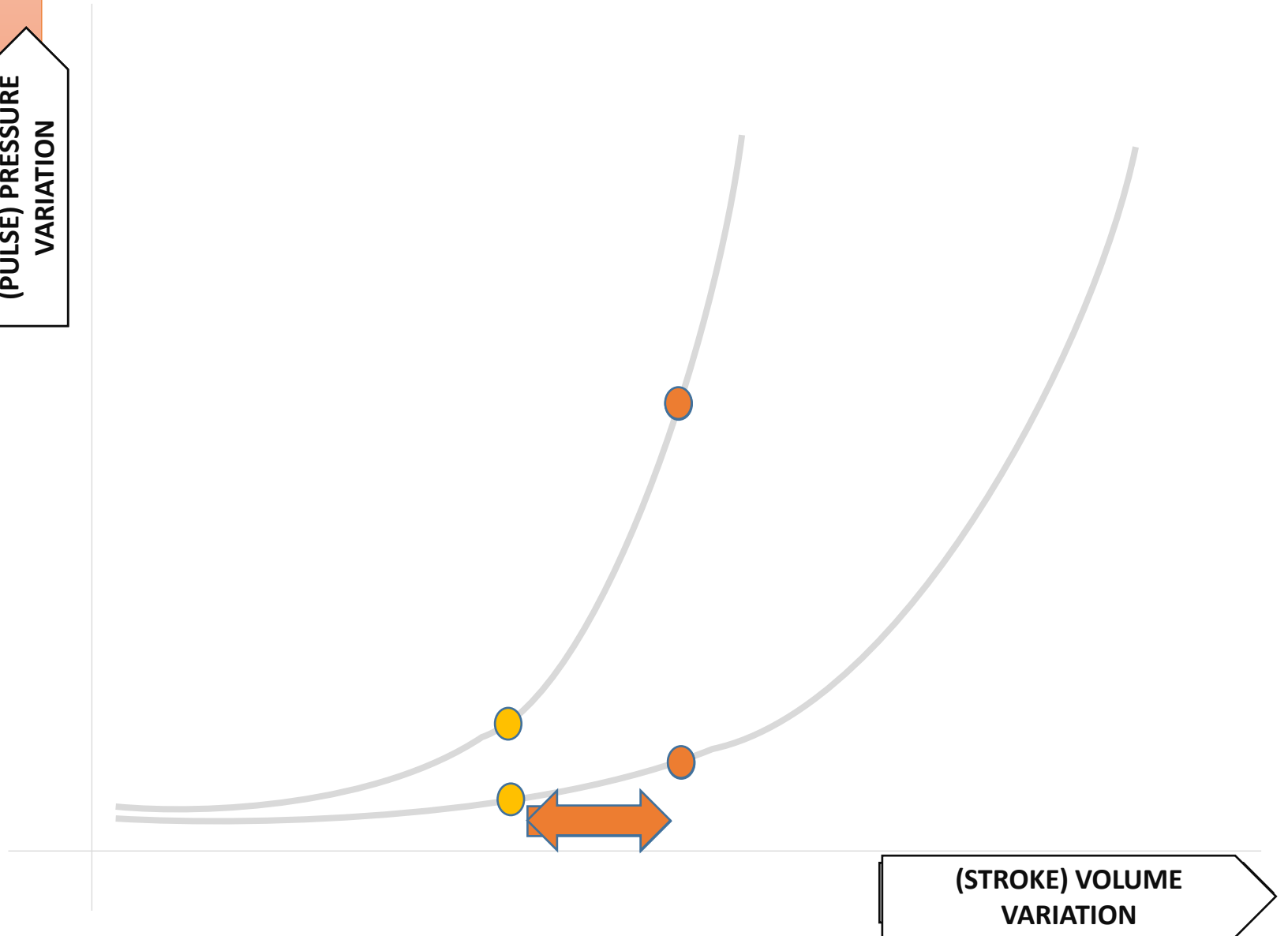
ARTERIAL TONE



$$SVRI \approx (MAP - CVP) / CO$$

GONE DYNAMIC ELASTANCE

(PULSE) PRESSURE
VARIATION

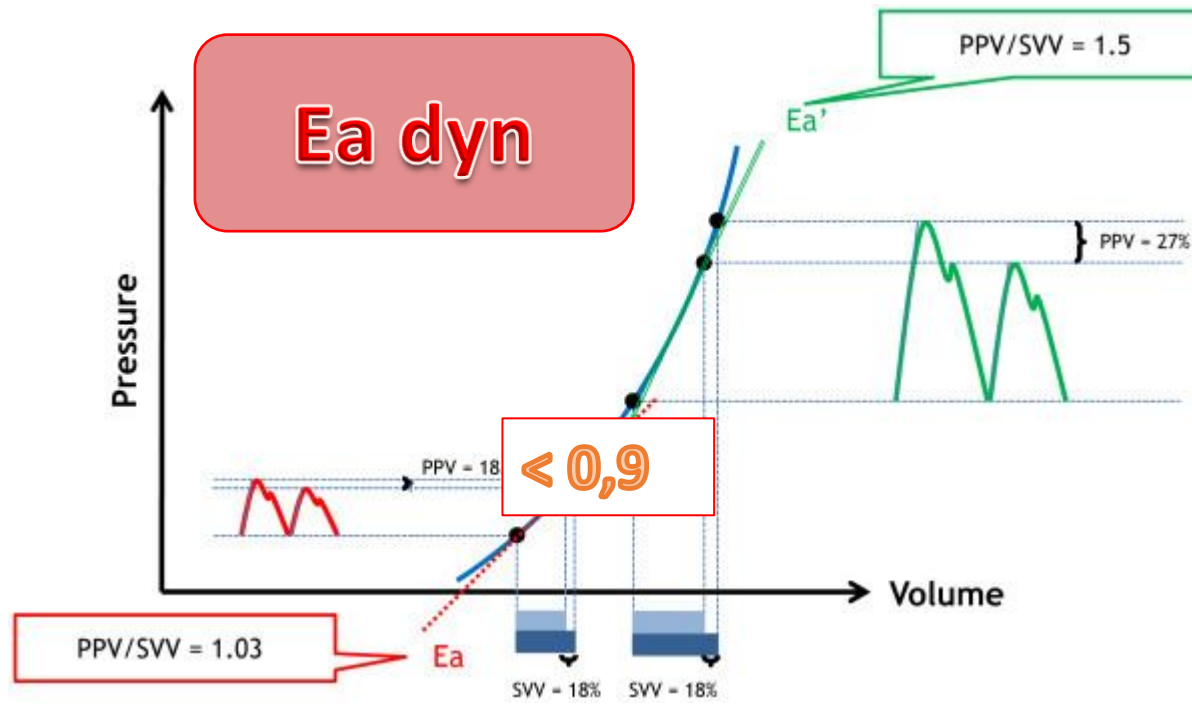


DYNAMIC ELASTANCE

CLINICAL INVESTIGATION

Dynamic arterial elastance measured by uncalibrated pulse contour analysis predicts arterial-pressure response to a decrease in norepinephrine

S. Bar^{1,*}, F. Levie¹, O. Abou Arab¹, L. Badoux¹, Y. Mahjoub^{1,2}, H. Dupont^{1,2}, E. Lorne^{1,2} and P.-G. Guinot³



Indications of norepinephrine treatment, n (%)	
Cardiac postoperative vasoplegic syndrome	14 (40)
Sepsis	14 (40)
Haemorrhage shock	5 (14)
Polytrauma	2 (6)

Hypotension Probability: 71 %

P(↓BP)

5 Minute % Change

↑ 137%
(5 min)

71

P(↓BP)

MAP

mmHg

74

↓ 14%

CO

L/min

3.7

↓ 18%

SVR

dyne-s/cm²

1133

↑ 4%

↑ 13%
(5 min)

12

SWV

PR

bpm

67

↑ 3%

SV

mL/b

55

↓ 21%

SVV

%

12

↑ 13%

Stroke Volume Variation

dP/dt

mmHg/s

364

↓ 10%

LV Contractility

Ea_{dyn}

0.9

↑ 12%

Dynamic Elastance

↓ 18%
(5 min)

3.7

CO

L/min

10:21:35 pm

02/15/2017

FloTrac

20

🔒

Dynamic arterial elastance measured by uncalibrated pulse contour analysis predicts arterial-pressure response to a decrease in norepinephrine

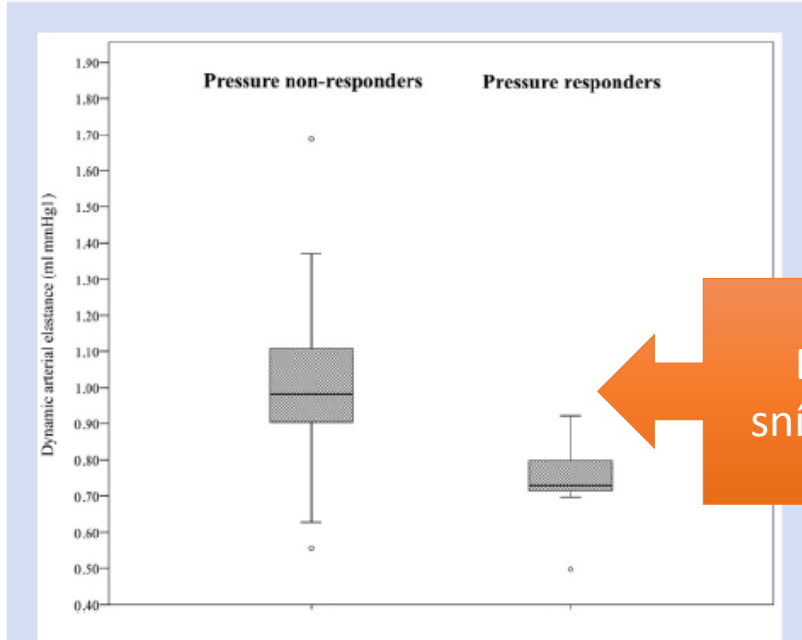
S. Bar^{1,*}, F. Leviel¹, O. Abou Arab¹, L. Badoux¹, Y. Mahjoub^{1,2}, H. Dupont^{1,2}, E. Lorne^{1,2} and P.-G. Guinot³

ORIGINAL



Monitoring dynamic arterial elastance as a means of decreasing the duration of norepinephrine treatment in vasoplegic syndrome following cardiac surgery: a prospective, randomized trial

Pierre-Grégoire Guinot^{1,2*}, Osama Abou-Arab¹, Mathieu Guilbart¹, Stéphane Bar¹, Elie Zogheib¹, Mona Daher¹, Patricia Besserve¹, Joseph Nader^{2,3}, Thierry Caus^{2,3}, Saïd Kamel², Hervé Dupont^{1,2} and Emmanuel Lorne^{1,2}



Pád MAP po snížení dávky NA

Fig 2. Dynamic arterial elastance distribution according to the response of arterial pressure with norepinephrine decrease.

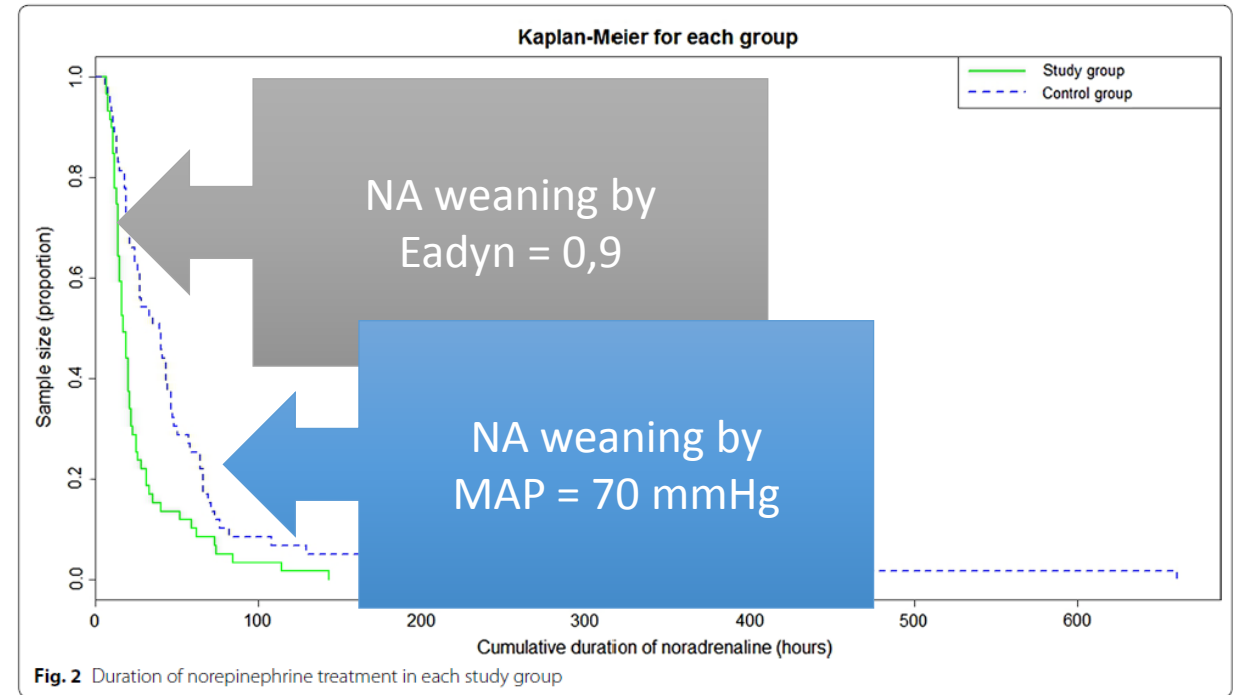


Fig. 2 Duration of norepinephrine treatment in each study group

KONTRAKTILITA
=
INOTROPIE

Contractility

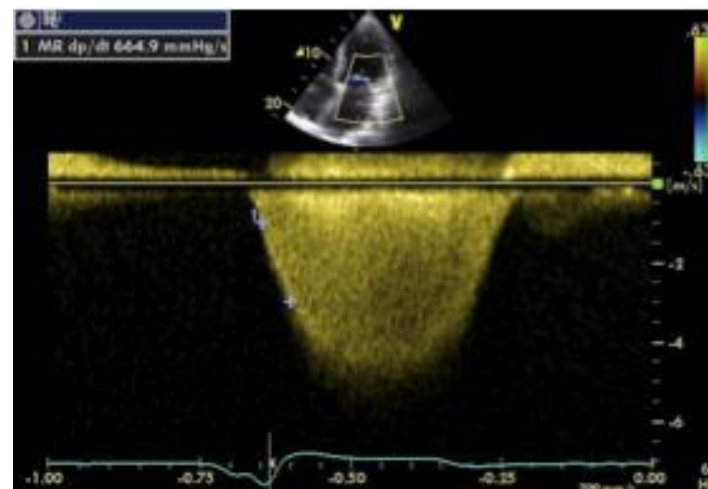
dP/dt Calculation

Velocity 1 (V_1)

Velocity 2 (V_2)

Time 1 (T_1) Time 2 (T_2)

$$dP/dt = ((4V_1^2) - (4V_2^2)) / (T_2 - T_1)$$



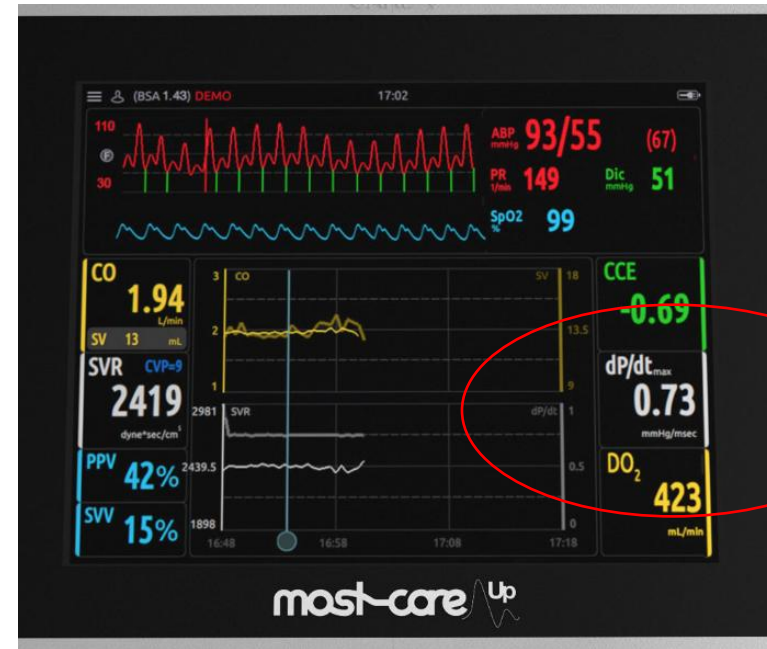
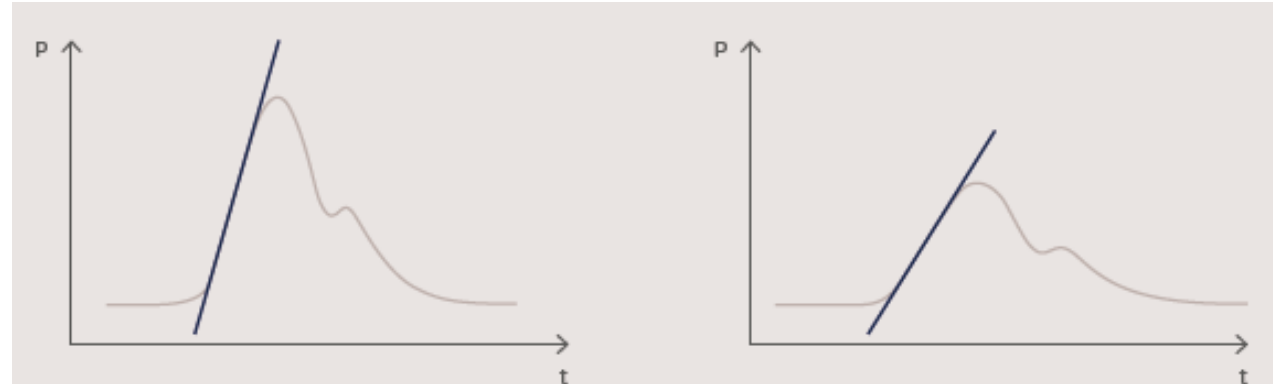
NORMÁLNÍ > 1200 mmHg/s

HRANIČNÍ 800-1200 mmHg/s

SNÍŽENÁ < 800 mmHg/s

KONTRAKTILITA
=
INOTROPIE

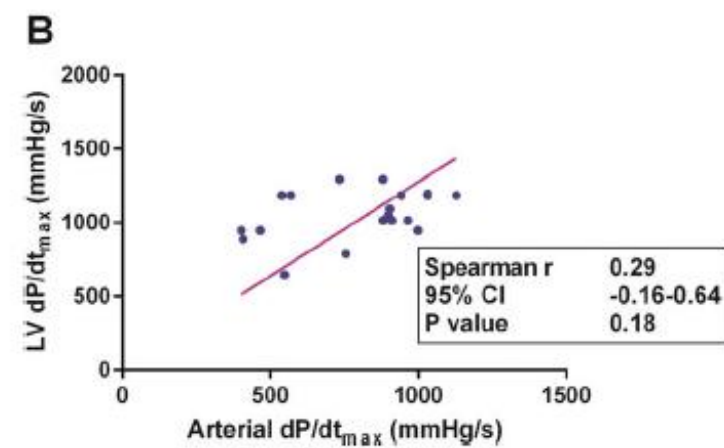
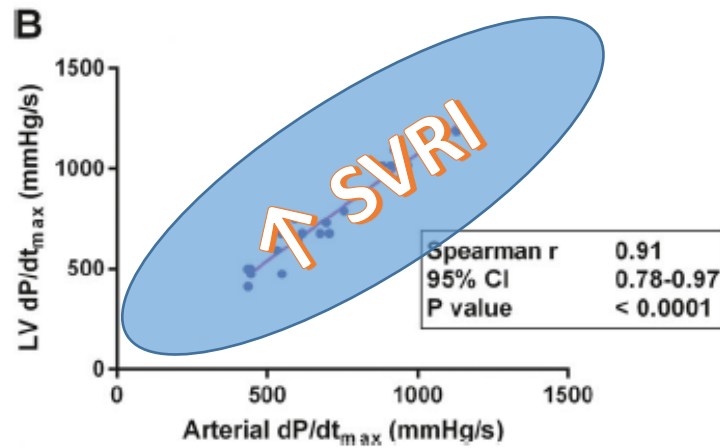
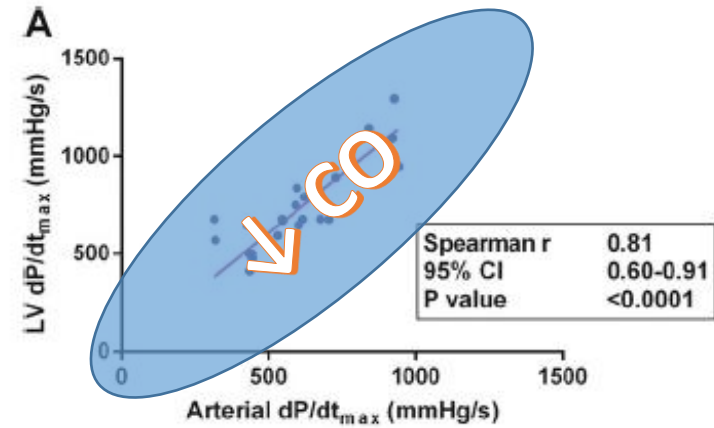
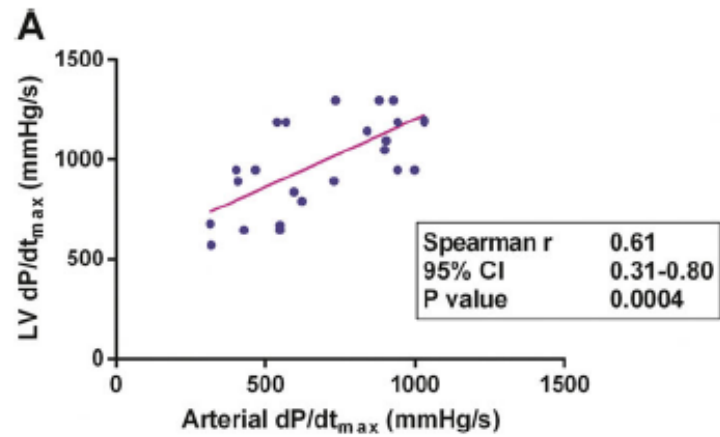
$$dP_{max} = dP/dT$$



Continual measurement of arterial dP/dt_{max} enables minimally invasive monitoring of left ventricular contractility in patients with acute heart failure

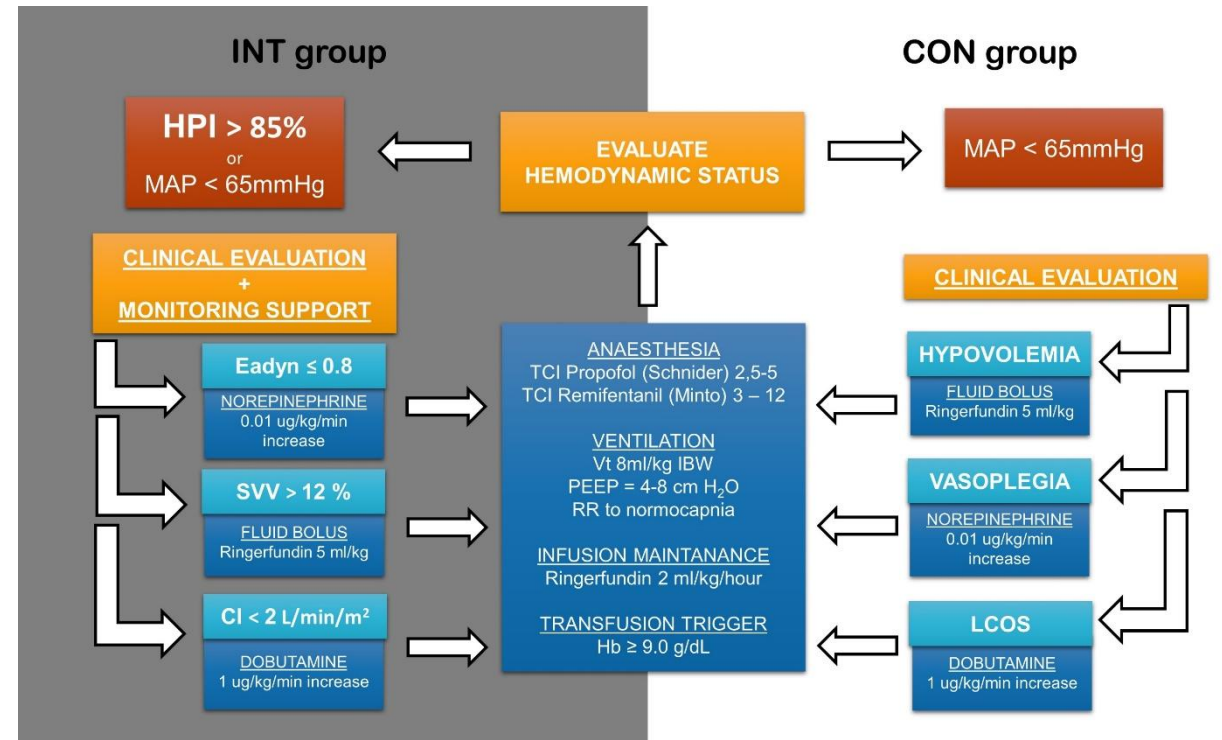
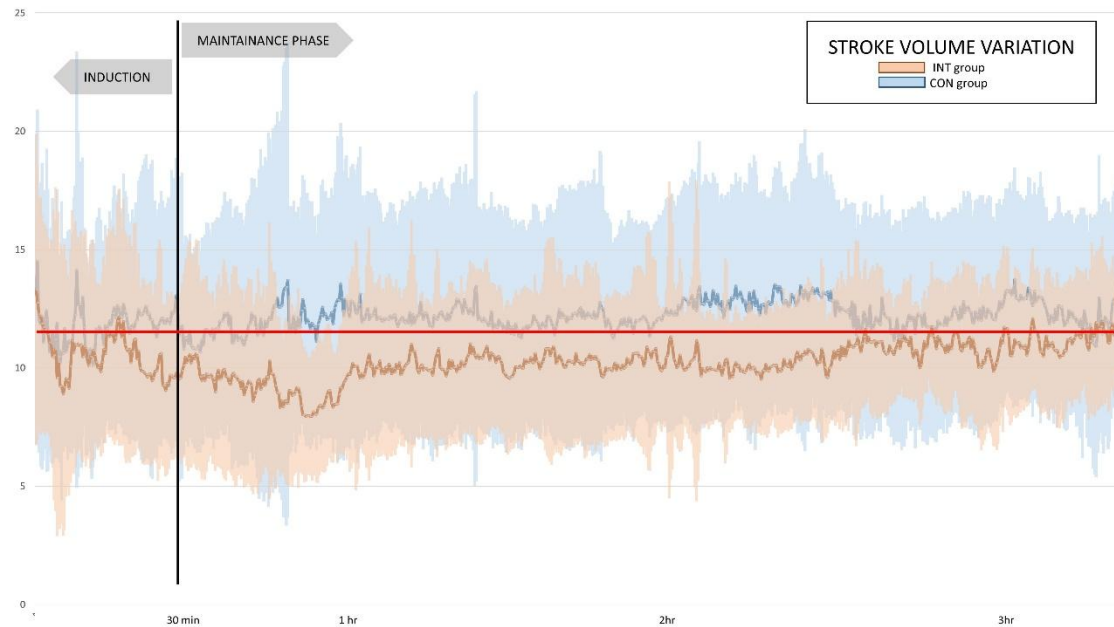
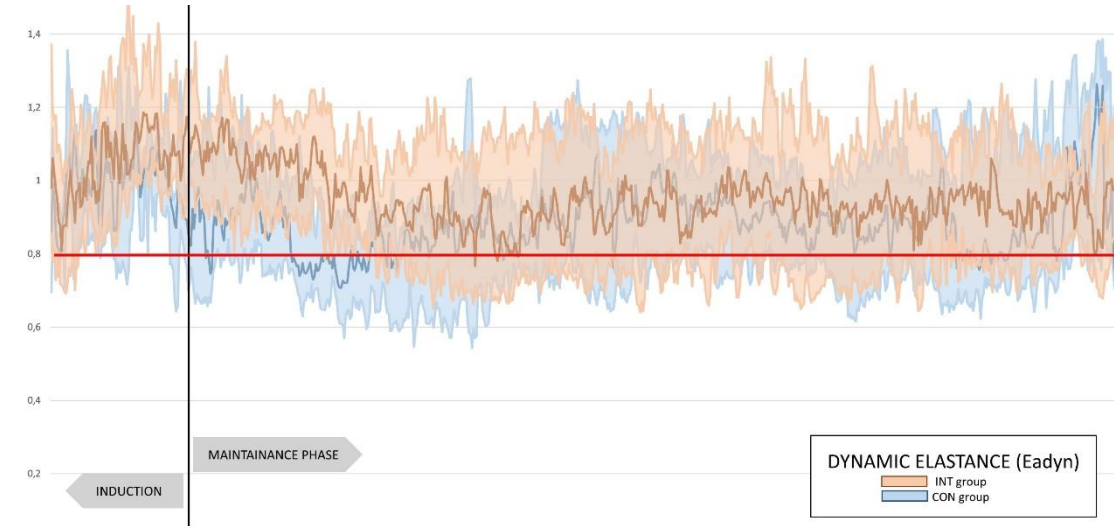


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**NIŽŠÍ EXPOZICE HYPOTENZII PŘI
EKVIVALENTNÍM MNOŽSTVÍ PODANÝCH
TEKUTIN A NIŽŠÍ KUMULATIVNÍ DÁVCE
NORADRENALINU**

Odvozené parametry ...

- Variace v čase
 - významný indikátor tekutinové reaktivity ZA PODMÍNKY... „LIMITS“
- Dynamická elastance
 - zajímavý nový parametr
- Tlaková akcelerace (dP/dt)
 - možná „trendy“

Každopádně křivka
arteriálního tlaku v sobě
skýtá netušené rozměry ...

DĚKUJI ZA
POZORNOST

