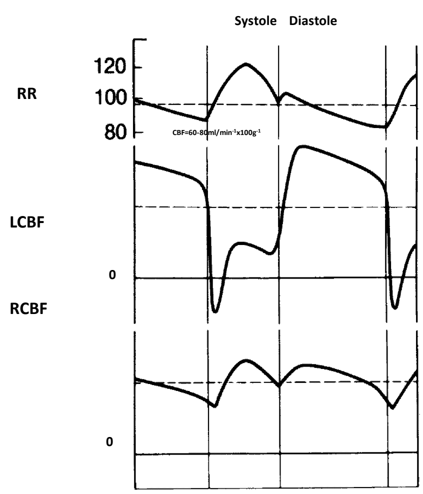
Herz-Kreislauf Physiologie
von den Grundlagen in die Praxis

Prim. Univ. Prof. Dr. Walter Hasibeder
Abt. f. Anästhesie und Operative Intensivmedizin
St. Vinzenz Krankenhaus Zams



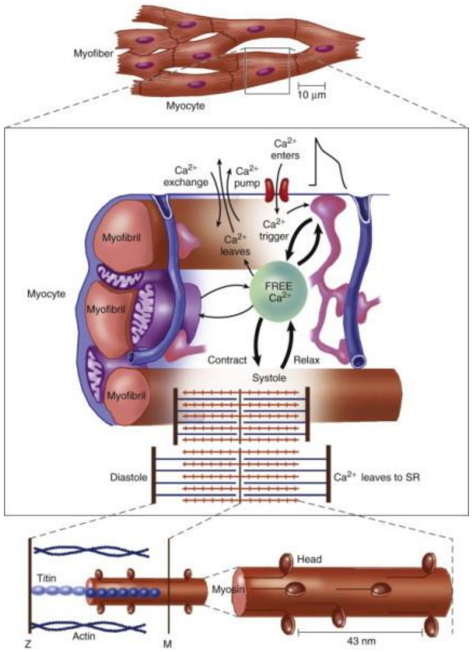
DAS HERZ:

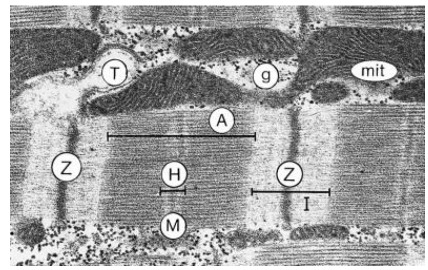
- verbraucht 6kg ATP/Tag
- schlägt 100.000x/Tag (ca. 2 Milliarden mal/Leben)
- pumpt 10 Tonnen Blut/Tag

SUBSTRAT VERBRAUCH

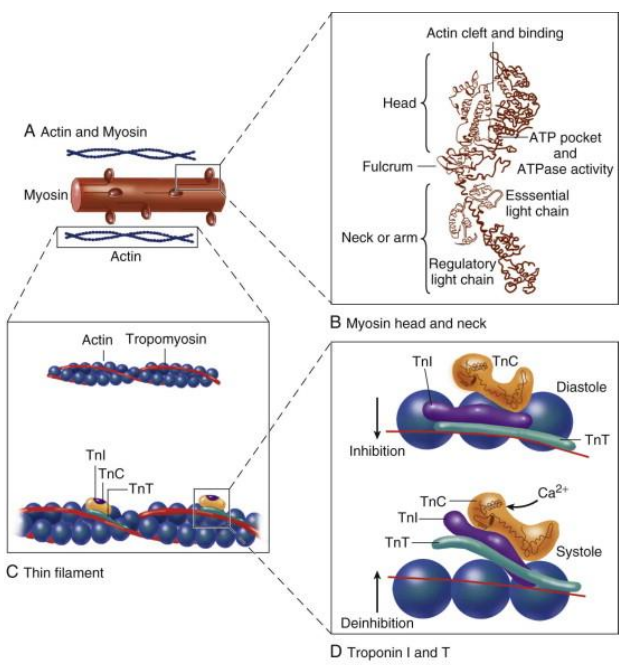
- Fettsäuren (60-90%)
- Glukose (10-40%)

VO_2 = 7-9ml/(min x 100g)
ERO_2 = 60%-70%





Sarcomer = Abschnitt zwischen 2 Z-Linien
H = Zentrale Zone mit nur Myosinfilamenten
A = Zone mit Aktin- und Myosinfilamenten
I = Zone mit Aktin, Titin und Z-Scheiben
G = Glycogen Granula
Mit = Mitochondrien



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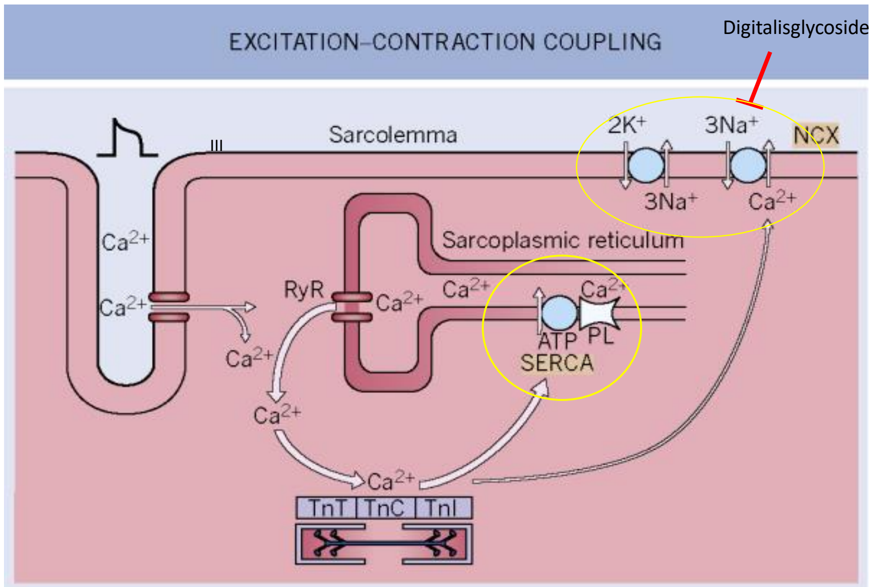
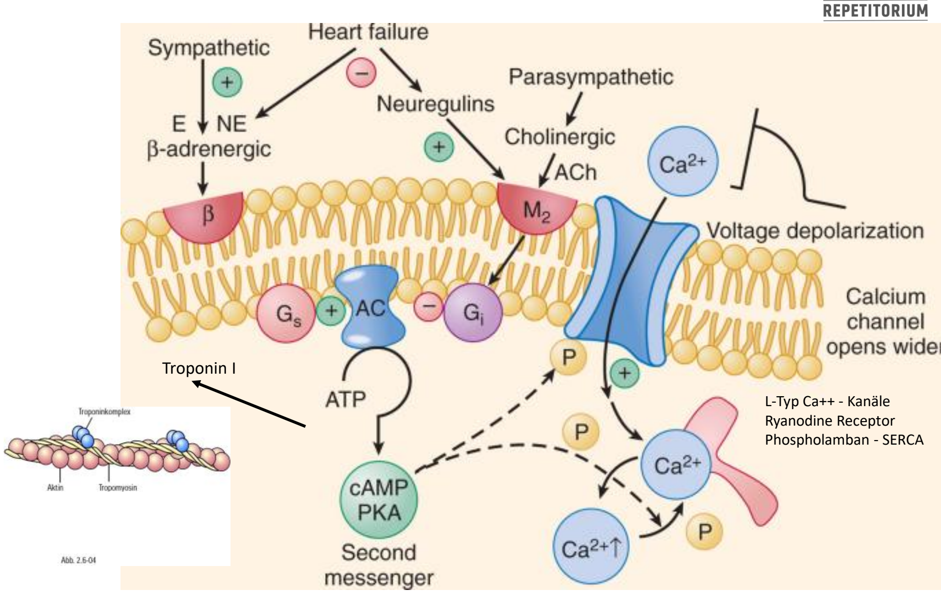
Opie LH: Heart Physiology, From Cell to Circulation. Philadelphia, Lippincott Williams & Wilkins, 2004

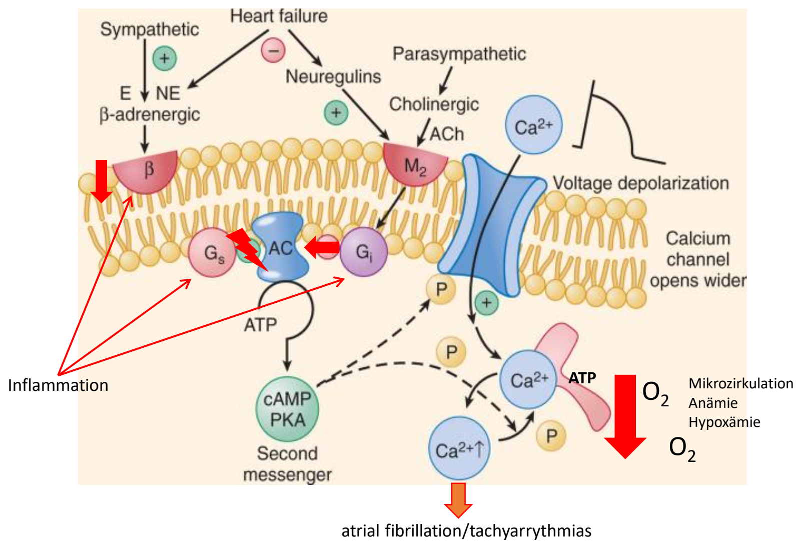
ANÄSTHESIE FORUM ALPBACH REPETITORIUM



ANÄSTHESIE FORUM ALPBACH REPETITORIUM



ß-adrenoadrenerge Mechanismen am Herzen in der Sepsis



HERZMECHANIK

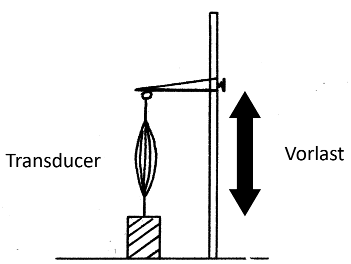
Vorlast

Nachlast

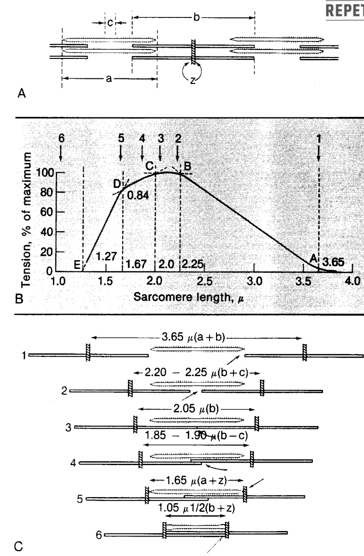
Kontraktilität (Inotropie)

VORLAST = PRELOAD

ISOMETRISCHE MUSKELPRÄPERATION

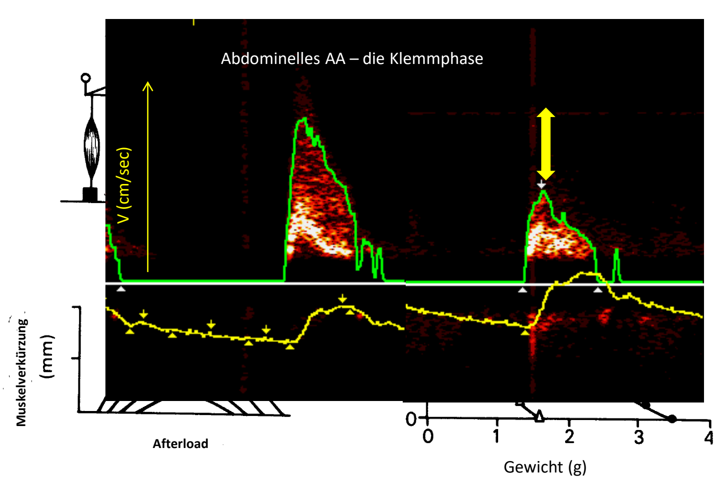


Vorlast = Muskelvordehnung

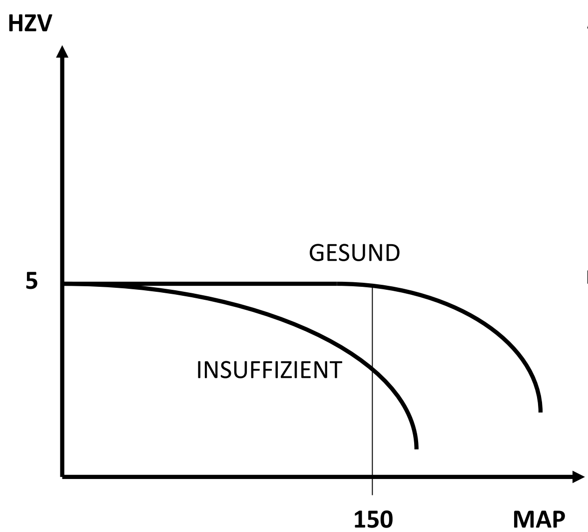


NACHLAST = AFTERLOAD

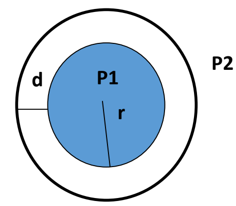
AFTERLOAD = WIDERSTAND GEGEN DEN DAS HERZ SEINE SCHLAGVOLUMENSARBEIT VERRICHTEN MUß; GEWICHT DAS EIN MUSKEL BEWEGEN MUß



EIN GESUNDES LINKES HERZ ARBEITET WEITGEHEND AFTERLOADUNABHÄNGIG

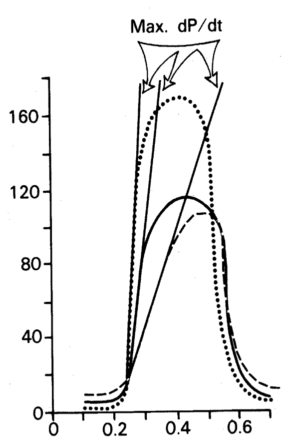


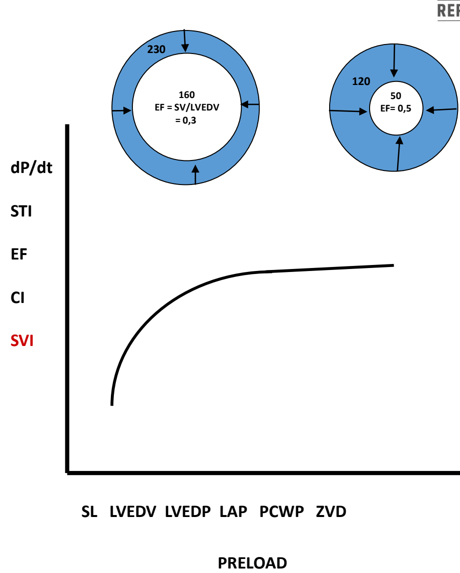
AL = ((P1-P2) x r)/d

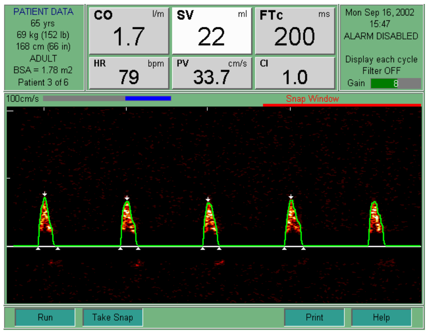


Hauptdeterminante des AL = MAP

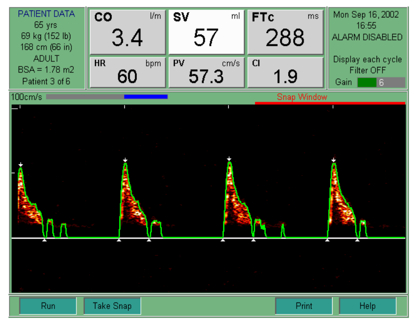
KONTRAKTILITÄT





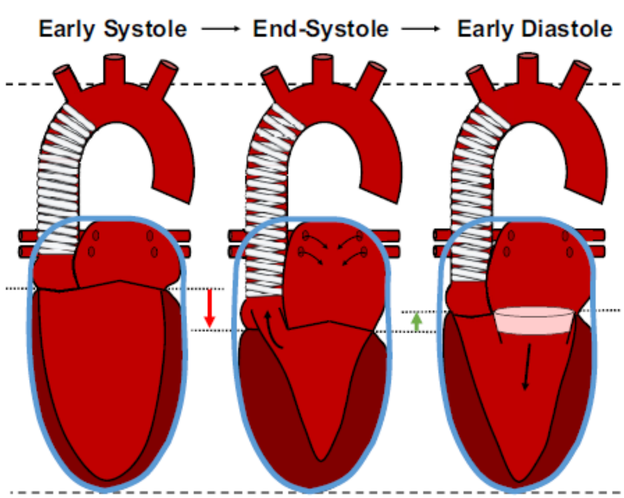


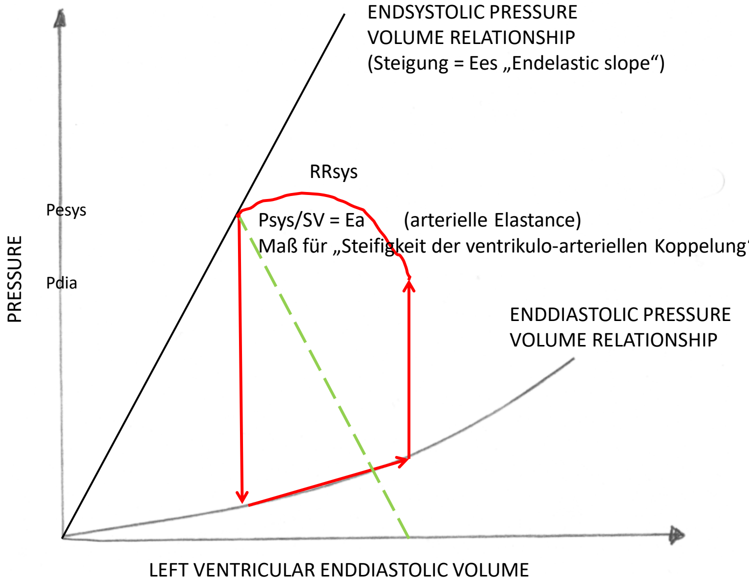
Patient mit Kontraktilitätsproblem
vor Therapie mit Dobutamine



Patient mit Kontraktilitätsproblem
nach Therapie mit Dobutamine

Aortic stiffness, pressure and flow pulsatility, and target organ damage
Mitchell GF. J Appl Physiol 2018; 125: 1871-1880

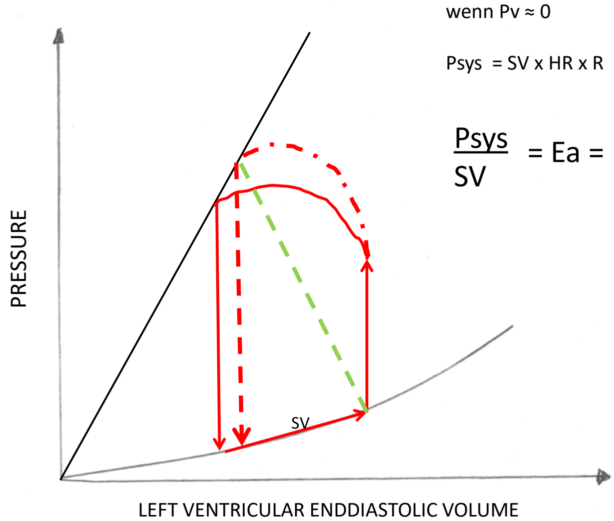




P = (SVxHR) x R
wenn Pv ≈ 0

Psys = SV x HR x R

$$\frac{Psys}{SV} = Ea = HR \times R$$

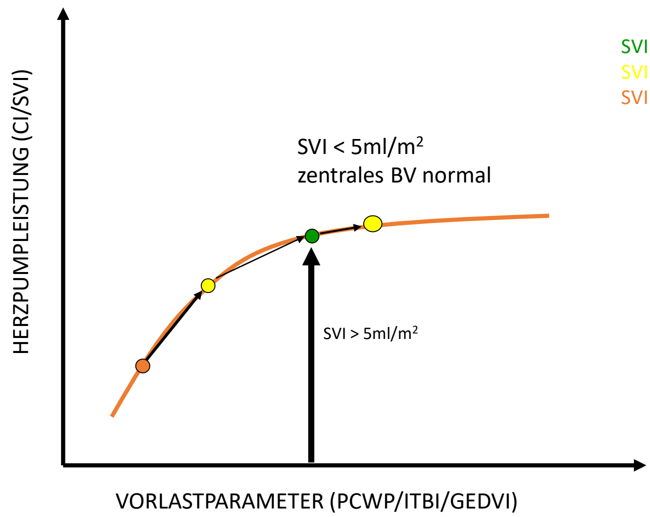


KLINISCHE BEURTEILUNG DES ZENTRALEN BV UND DER HERZPUMPFUNKTION

SVI normal > 40ml/m²

SVI ausreichend > 30ml/m²

SVI schlecht < 25ml/m²

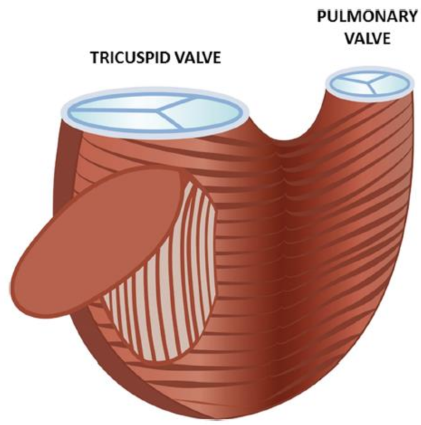


RECHTER VENTRIKEL

- 1/3 der linksventrikulären Muskelmasse
- 1/4 des linksventrikulären „Stroke Work (MPAPxSV)“
- Ca. 10-15% größeres enddiastolisches Volumen
- große diastolische Compliance
- systolische Kontraktion führt vor allem zur longitudinalen Verkürzung
- 40% der systolischen Funktion ist von einem intakten Septum abhängig

Right ventricular mechanical pattern in health and disease beyond longitudinal shortening

Kovacs A, Lakatos B, et al. Heart Failure Reviews 2019; 24: 511-520



- Beginn Kontraktion am Infundibulum
- initial zirkumferente Kontraktion (Einwärtsbewegung der freien Ventrikelwand und Kontraktion des IVS in das rechte Ventrikelkavuum)
- in der Systole longitudinale Kontraktion (Zug der TK gegen den Apex)

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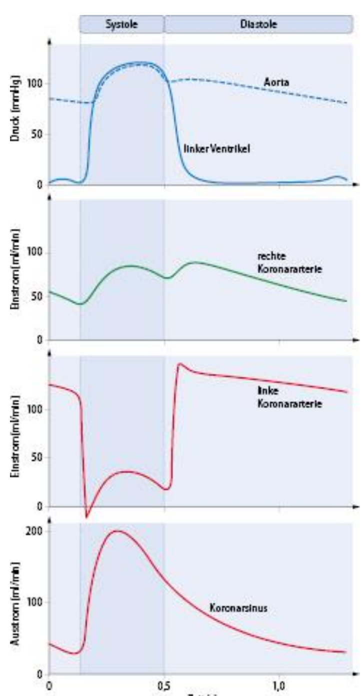
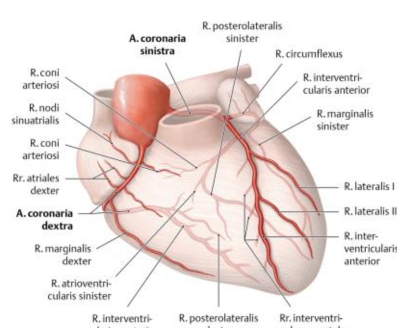


RECHTSHERZDURCHBLUTUNG

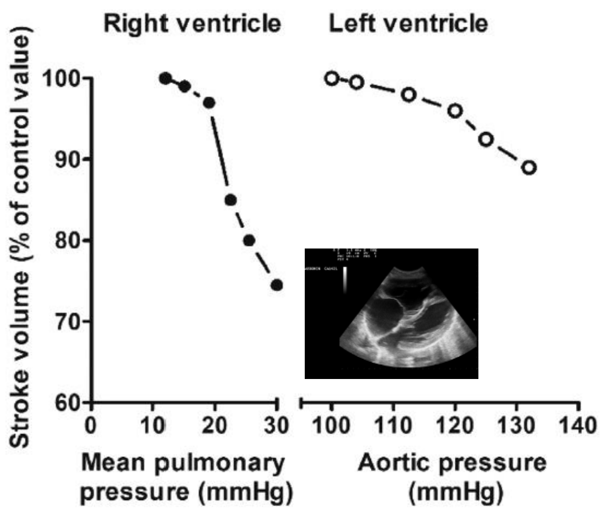
Rechte KA
Freie Wand; hinteres Drittel des interventrikulären Septums

Linke KA
Apex und vorderes interventrikuläres Septum



EFFEKTE DER NACHLASTERHÖHUNG AUF DEN RECHTEN UND LINKEN VENTRIKEL

ANÄSTHESIE FORUM ALPBACH REPETITORIUM

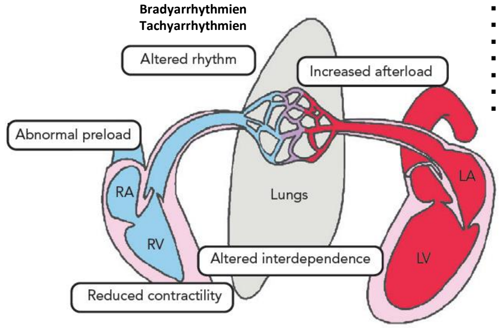


ANÄSTHESIE FORUM ALPBACH REPETITORIUM

- Hypo- Hypervolämie
- Linksherzinsuffizienz
- Perikardtamponade
- Mechanische Beatmung
- Links-rechts Shunt

- RV Ischämie/Infarkt
- SIRS/Sepsis
- Myokarditis
- Kardiomyopathie
- Herzrythmusstörungen

Bradyarrhythmien
Tachyarrhythmien



LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle.

- Linksherzversagen
- Pulmonalembolie
- Pulmonal arterielle Hypertension
- Akute Lungenerkrankungen
- Schlaf-assoziierte Ventilationsstörungen
- Mechanische Beatmung mit hohen Drücken
- Ausflusstraktstenose z.B. nach Korrektur eines angeborenen Vitiums

- Pericardtamponade
- Pericarderkrankungen
- Septumshift

FUNKTIONELLE HERZKREISLAUFPHYSIOLOGIE

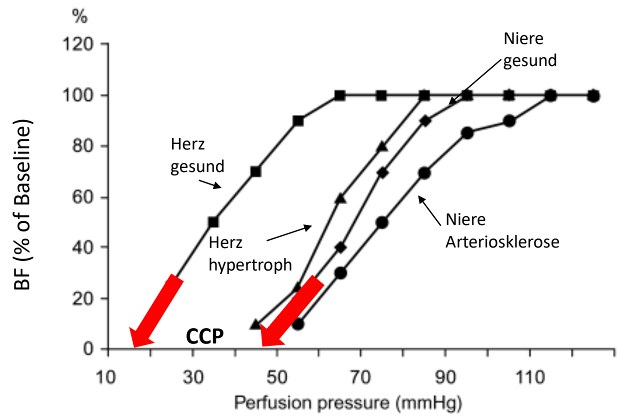
Das Herzkreislaufsystem
und
seine Limits

BLUTDRUCK

UNTERGRENZE AUTOREGULATION (gesund)

NIERE 70 mmHg (Shipley and Study 1951)
ZNS 50 mmHg (Lassen 1959)
GIT 50 mmHg ?? (Johnson 1964)
HERZ 40 mmHg (Rubio and Berne 1975)
HAUT, MUSKEL, PERIPHERE NERVEN ??

AUTOREGULATIONSKURVEN



Bellomo R. Heart,Lung and Circulation 2003: S42

The arterial blood pressure associated with terminal cardiovascular collapse In critically ill patients: a retrospective cohort study

Brunauer A, Koköfer A, Bataar O, et al. Crit Care 2014; 18:719

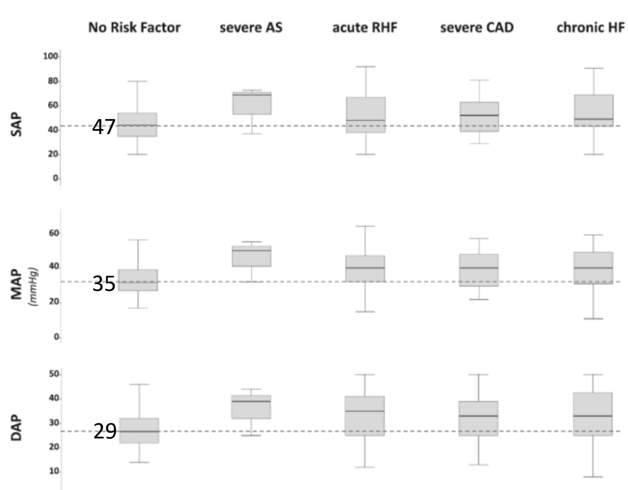
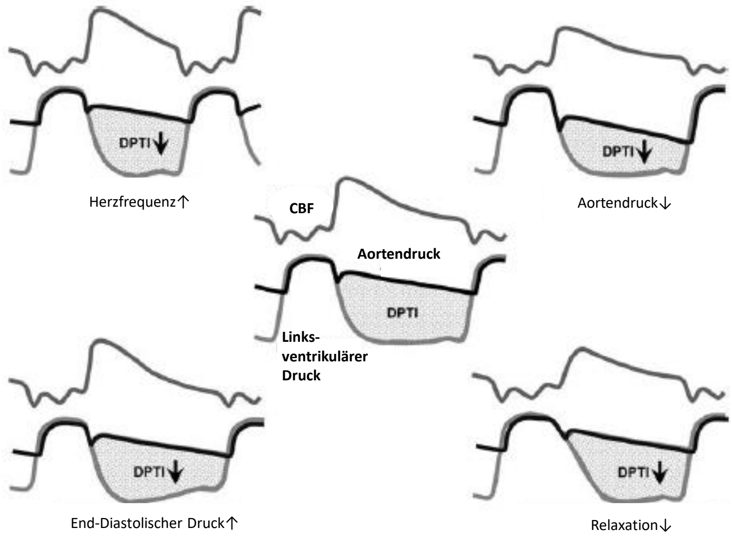


Figure 2 Box plots showing arterial blood pressures associated with terminal cardiovascular collapse in patients with and without specific risk factors. AS, Arterial stenosis; CAD, Coronary artery disease; DAP, Diastolic arterial pressure; HF, Heart failure; MAP, Mean arterial pressure; RHF, Right heart failure; SAP, Systolic arterial pressure. Boxed areas indicate median values with interquartile ranges. Error bars indicate minimum and maximum values. The dashed lines represents median values in patients with no risk factor.

DPTI – Diastolic Pressure Time Index



Buckberg GD et al. Circ Res 1972; 30:67-81
Gallagher KP et al. Am J Physiol 1984; 247: H727-H738

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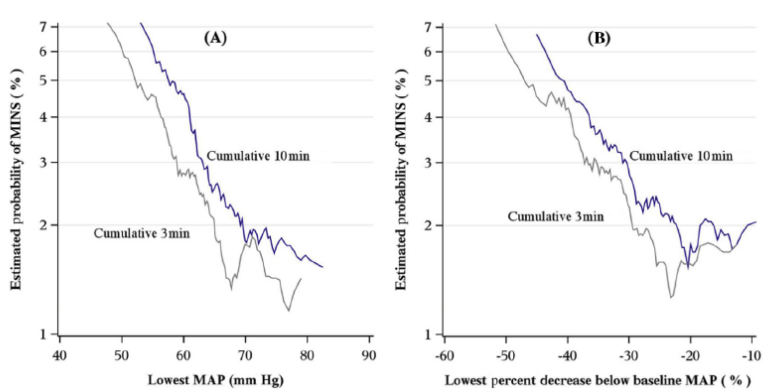
Relationship between intraoperative hypotension, defined by either reduction from reduction from baseline or absolute threshholds, and acute kidney and myocardial injury after noncardiac surgery

Salmasi V, Maheshwari K, et al. Anesthesiology 2017; 126: 47-65

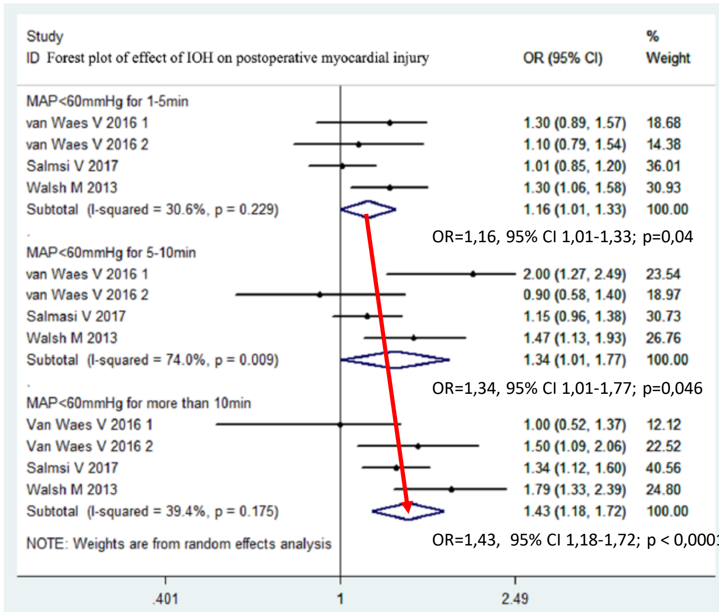
N = 57.315 MINS: n=1760 Non-MINS = 55.555



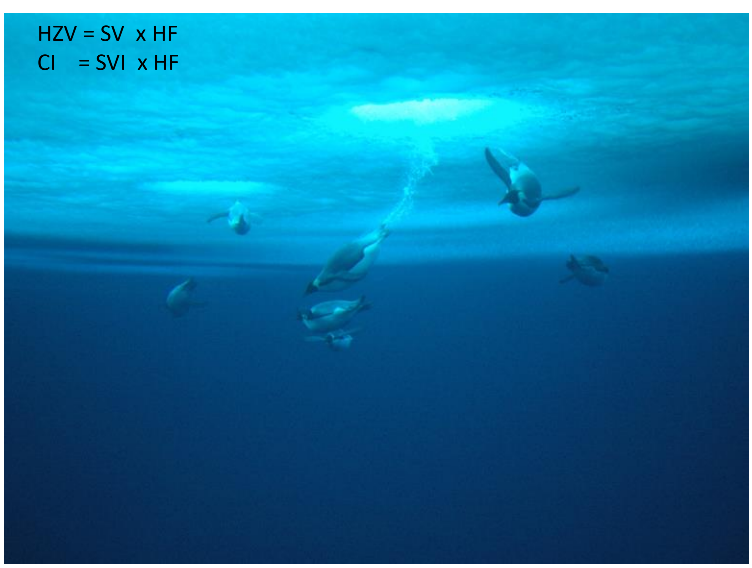
Relative MAP-Veränderungen haben keinen höheren Prädiktionswert als absolute MAP-Werte
Absolute MAP-Veränderungen erweisen sich aber in der Klinik praktikabler

Association of Intraoperative Hypotension with Acute Kidney Injury, Myocardial Injury And Mortality in Noncardiac Surgery: A Metaanalysis

Ran An, Pang QY, Liu HL. Int J Clin Pract. 2019: e13394



BLUTFLUSS



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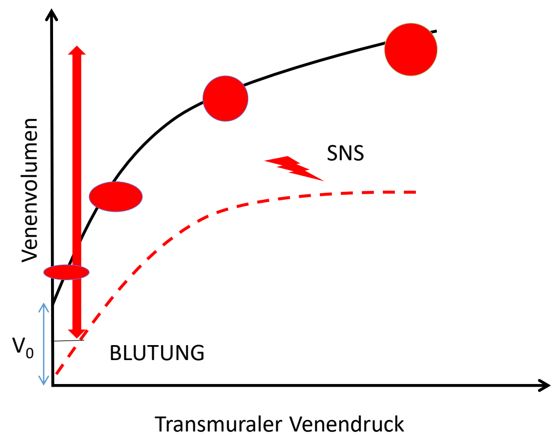
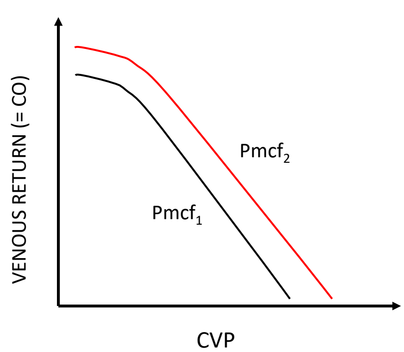
DAS VENÖSE SYSTEM



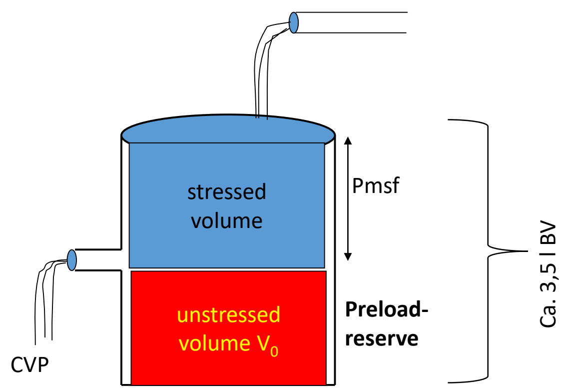
DER MITTLERE ZIRKULATORISCHE FÜLLUNGDRUCK



CO = (Pmcf-CVP)/Rven

dVR

DER MITTLERE ZIRKULATORISCHE FÜLLUNGDRUCK



65%-70% unseres BV befinden sich im venösen Gefässsystem außerhalb des Thorax!
Das intrathorakale BV beträgt hingegen nur etwa 900 ml (Pulmonalgefäße und Herz)

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Changes in the Mean Systemic Filling Pressure during a Fluid Challenge in Postsurgical Patients

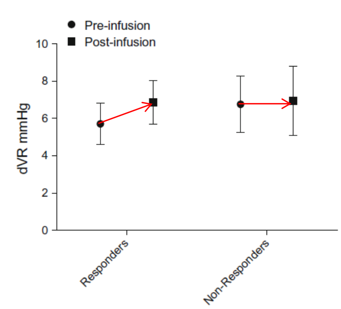
Cecconi M, et al. Int Care Med 2013;39:1299-1305

	Responders ($n = 43$)				Non-Responders ($n = 58$)			
	Pre-infusion	Post-infusion	Δ	p	Pre-infusion	Post-infusion	Δ	p
HR, bpm	88.8 ± 10.3	88.5 ± 10.3	0.2	0.5	88.3 ± 15.5	87.9 ± 14.7	0.4	0.3
MAP, mmHg	66 ± 7.3*	77.1 ± 9.8	11.1 ± 6.5*	<0.001	72.8 ± 12.7	76.6 ± 14.4	3.8 ± 4.8	<0.001
CO, L min^{-1}	3.8 ± 1.1*	4.4 ± 1.3	0.7 ± 0.3*	<0.001	4.9 ± 1.6	5 ± 1.7	0.1 ± 0.3	0.003
CVP, mmHg	12.1 ± 5.7	14.1 ± 5.5	2 ± 1.9*	<0.001	11.1 ± 5.3	14.1 ± 5.4	2.9 ± 1.7	<0.001
Pmsa, mmHg	17.8 ± 5.1	20.9 ± 5.1	3.1 ± 1.9	<0.001	17.9 ± 4.9	21 ± 4.9	3.1 ± 1.8	<0.001
dVR, mmHg	5.7 ± 1.1*	6.9 ± 1.2	1.16 ± 0.8*	<0.001	6.7 ± 1.5	6.9 ± 1.8	0.2 ± 1	0.15
Eh	0.35 ± 0.15	0.34 ± 0.12	−0.01 ± 0.04*	0.15	0.41 ± 0.15	0.34 ± 0.13	−0.06 ± 0.05	<0.001
RVR	1.5 ± 0.3	1.6 ± 0.3	0.0 ± 0.2	0.4	1.4 ± 0.3	1.4 ± 0.3	0.0 ± 0.2	0.9

39 postsurgical patients
101 fluid challenges (250ml)

Responders: SV ↑ > 10%

Measurements: SV; MAP; CVP
Calculations: Pmsa, dVR, Eh (Navigator®)



Does Central Venous Pressure Predict Fluid Responsiveness?*

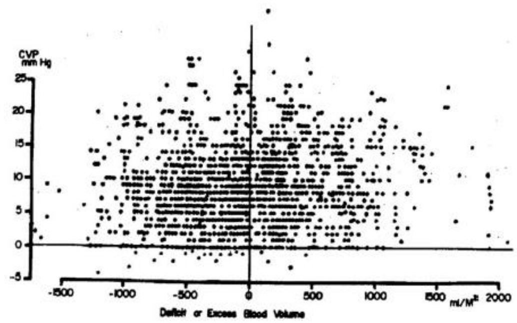
A Systematic Review of the Literature and the Tale of Seven Mares

Marik PE et al. Chest 2008;134:172-178

TABLE 1: Summery of Studies relating BV and CVP measurements

Source	Setting	Type	Patients, No.	Methodology	r, Blood Volume
Baek et al,[10] 1975	ICU	General surgery	69	^{125}I-albumin	0.19
Shippy et al,[11] 1984	ICU	ICU	118	^{125}I-albumin	0.27
Hoeft et al,[12] 1994	OR/ICU	CABG	11	Indocyanine green	0.12
Oohashi et al,[13] 2005	ICU	Esophagectomy	16	Indocyanine green	0.17
Kuntscher et al,[14] 2006	ICU	Burns	16	COLD system†	0.02
Pooled value					0.16

*OR = operating room; CABG = coronary artery bypass graft surgery.
†COLD Z-021 system (Pulston Medical Systems; Munich, Germany).



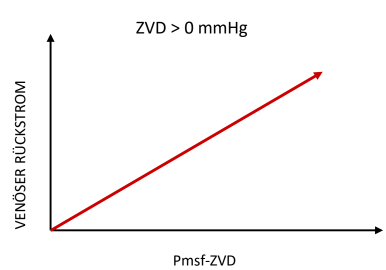
Shippy CR et al. Crit Care Med 1984;12:107-112

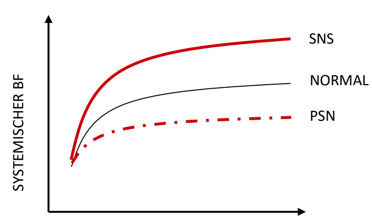
5 Studies
188 ICU patients
1500 measurements of BV and CVP with and without volume challenge

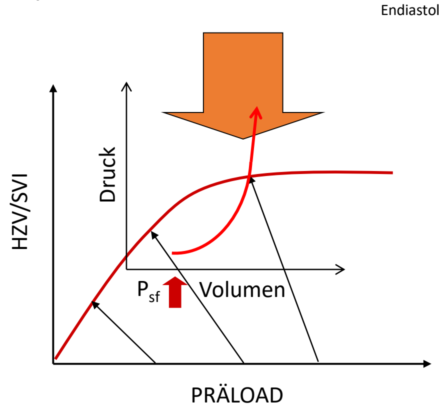
- No association between CVP and BV

- The correlation between changes in CVP and changes in BV was 0.1

Conclusion: Patients with low CVP may have a volume overload and vice versa!



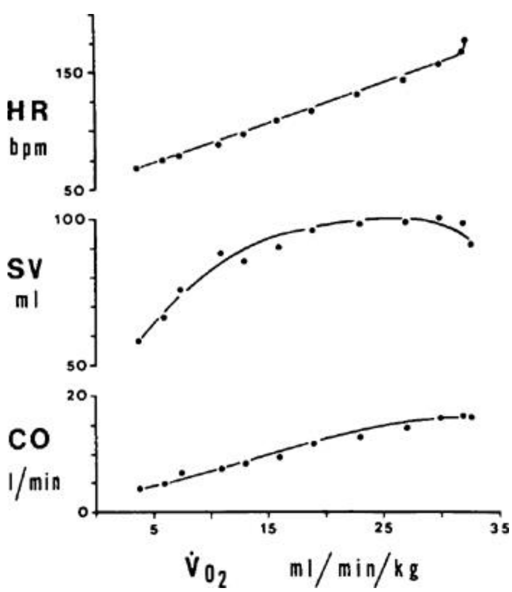




HERZKREISLAUFSYSTEM

ANPASSUNG AN STRESS

Janicki JS et at. Comprehensive Physiology 2011: 10.1002/cphy.cp120115



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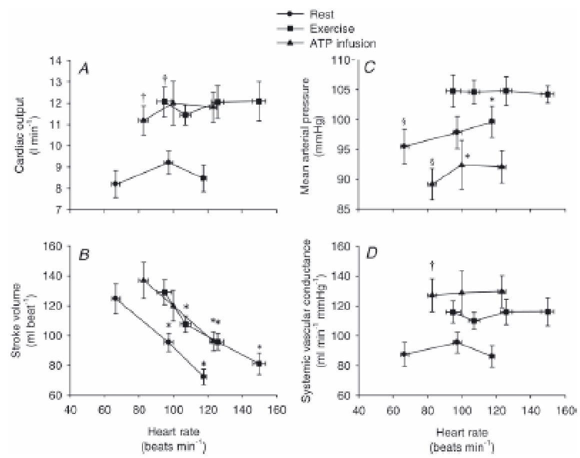
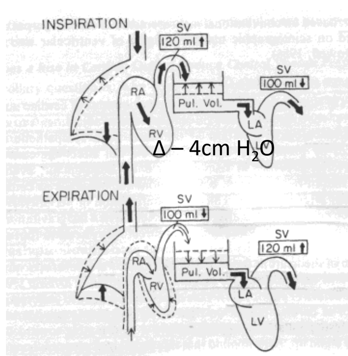
Peripheral vasodilatation determines cardiac output in exercising humans: insight from atrial pacing

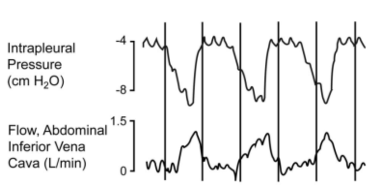
A. A. Bada[1], J. H. Svendsen[2,3], N. H. Secher[1,4], B. Saltin[1] and S. P. Mortensen[1]

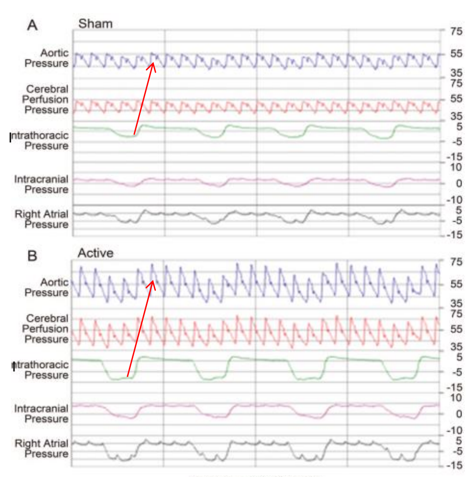


J Physiol 2012; 590.B: 2051-2060

DIE RESPIRATORISCHE PUMPE







Convertino VA et al. Optimizing the respiratory Pump: Harnessing inspiratory resistance to treat systemic hypotension. Respiratory Care 2011;56:846-857

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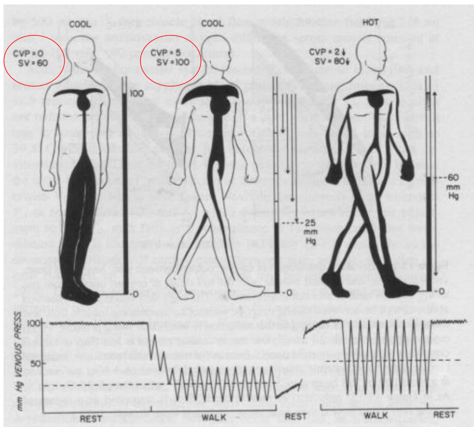
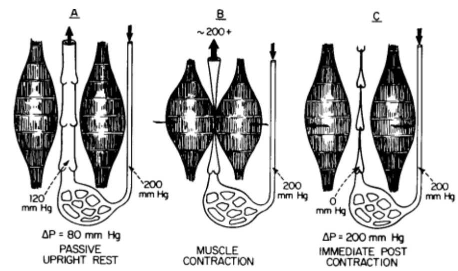
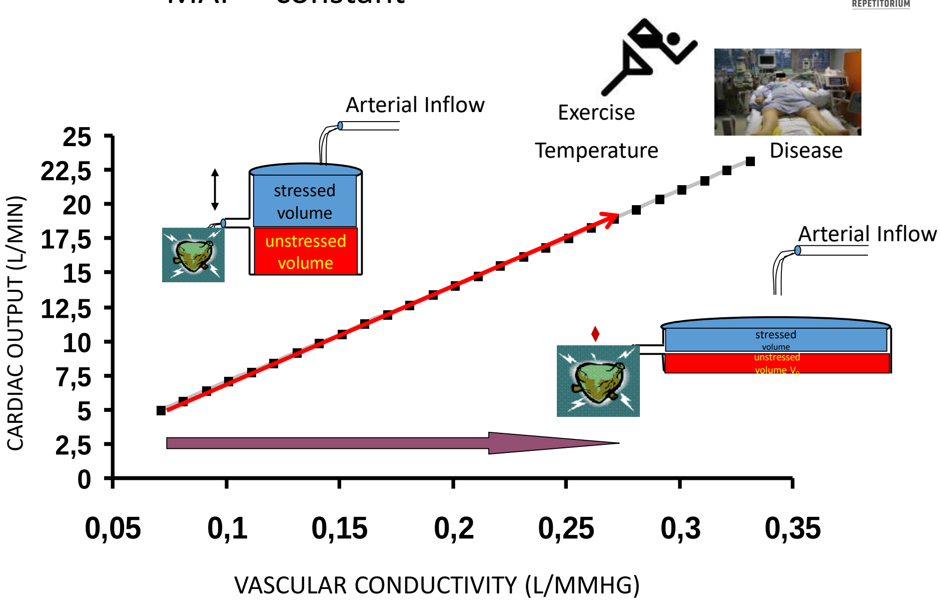
DIE MUSKELPUMPE





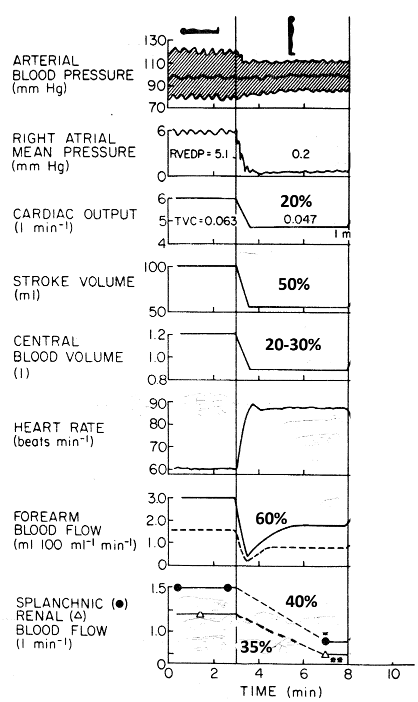
MAP ~ constant

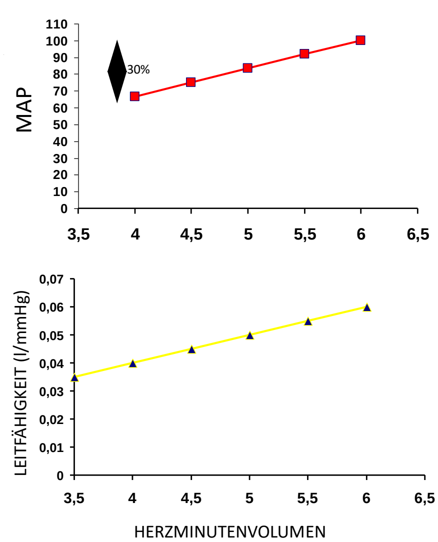


PERIPHERAL AND CENTRAL EFFECTS OF CIRCULATING CATECHOLAMINES

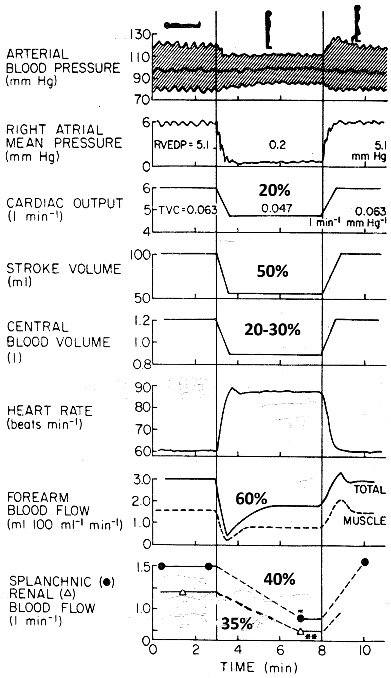
Tank AW and Wong DL
Compr Physiol 2015; 5:1-15

Stromgebiet	α 1 AR Arterielle und venöse Vasokonstriktion	α 2 AR Regulation der synaptischen Transmission im SNS Vasodilatation und Konstriktion	β 1 positive Chronotropie, Inotropie, Lusitropie, Bathmotropie, Stimulation des RAA-Systems	β 2 Arteriell und venöse Vasodilatation; positive Chronotropie, Inotropie, Bathmotropie	β 3 Metabolische Effekte „antagonistische" Effekte zu β 1 und β 2 AR
Aorta	+	+	+	+	+
Koronargefäße	++	+	+++	++	+
Pulmonalgefäße	++	+	++	++	+
Gehirn	+	-	+	+	-
Leber	++	+	+	++	+
Mesenterialgefäße	+++	++	++	+++	+
Niere	++	+	+	+	+
Muskulatur	+++	++	+	++	+
Haut	+++	+	+	++	+++

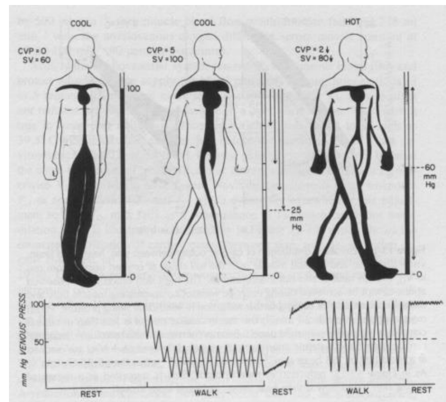


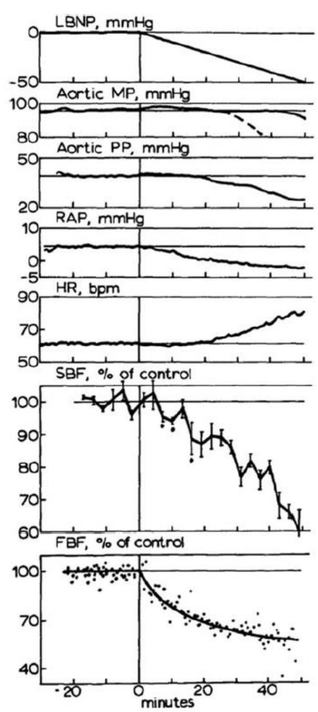


Culbertson 1951; Ring-Larsen 1982; Shepherd 1963
Rowell 1977;Johnson 1986



ANÄSTHESIE FORUM
ALPBACH
REPETITORIUM





ANÄSTHESIE FORUM
ALPBACH
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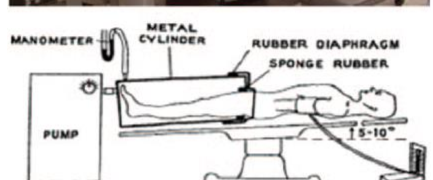
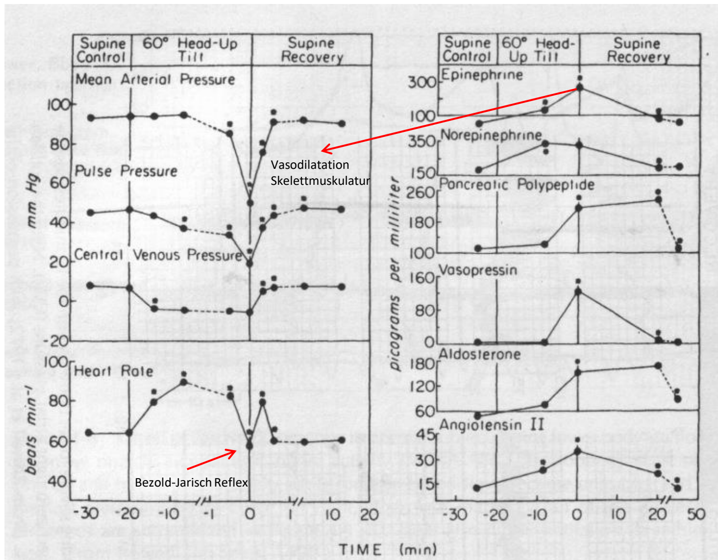
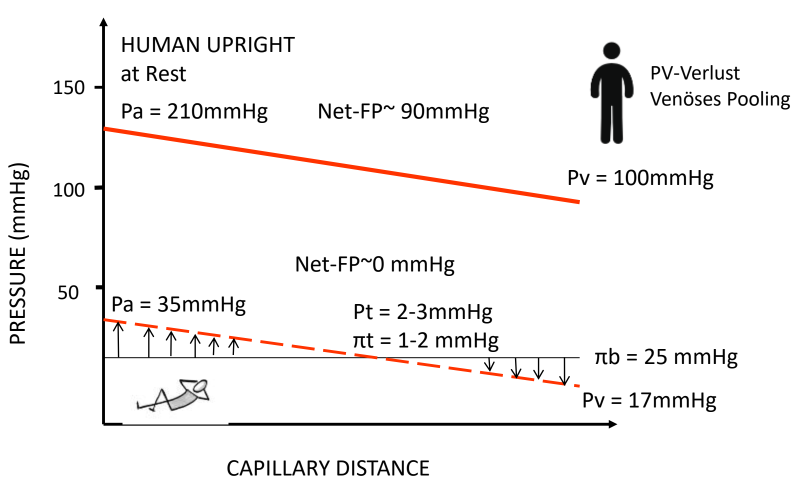




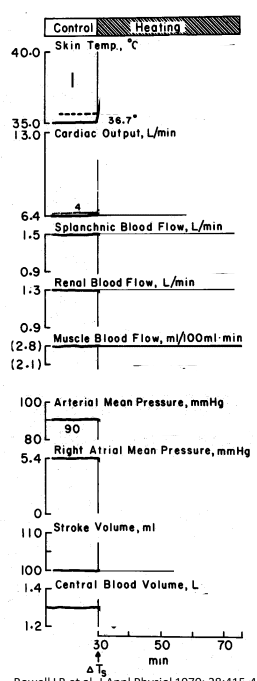
Sander-Jensen K et al. Am J Physiol 1986;251:R742-R748

KÖRPERLAGE UND ÖDEMFORMATION



Starling-Landis Gleichung: Q = Kf(Pa-Pv-Pt) – Ϭ(πb-πt)

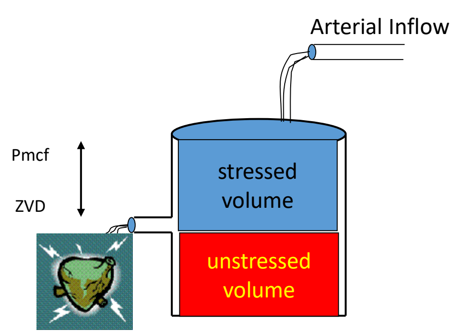
HITZESTRESS

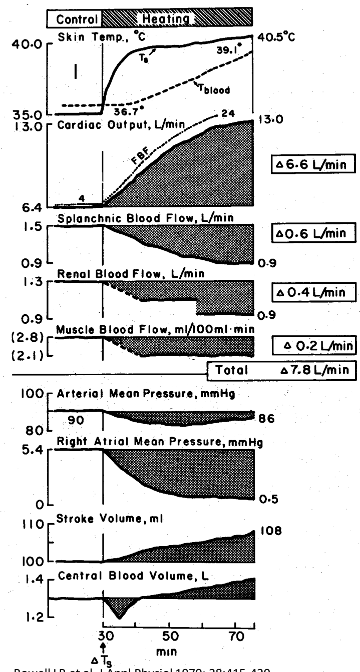


Rowell LB et al. J Appl Physiol 1970; 28:415-420
Rowell LB et al. J Appl Physiol 1971; 31:864-869

HERZKREISLAUFSYSTEM -HITZESTRESS

I = Baseline

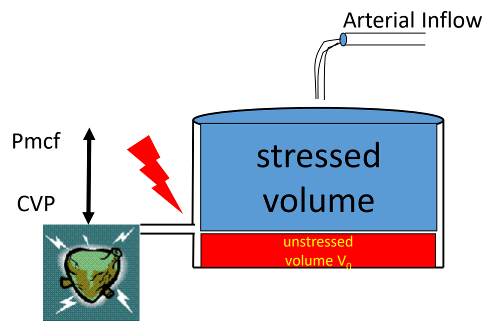




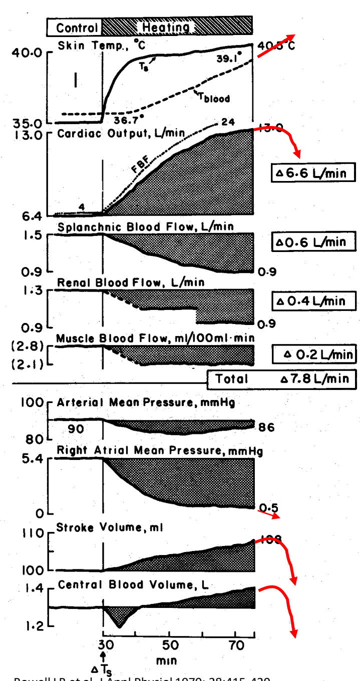
Rowell LB et al. J Appl Physiol 1970; 28:415-420
Rowell LB et al. J Appl Physiol 1971; 31:864-869

HERZKREISLAUFSYSTEM -HITZESTRESS

I = Baseline
II = Aufheizen



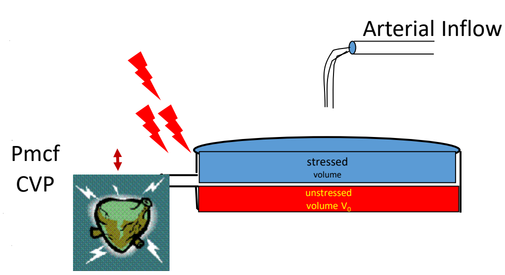
51



Rowell LB et al. J Appl Physiol 1970; 28:415-420
Rowell LB et al. J Appl Physiol 1971; 31:864-869

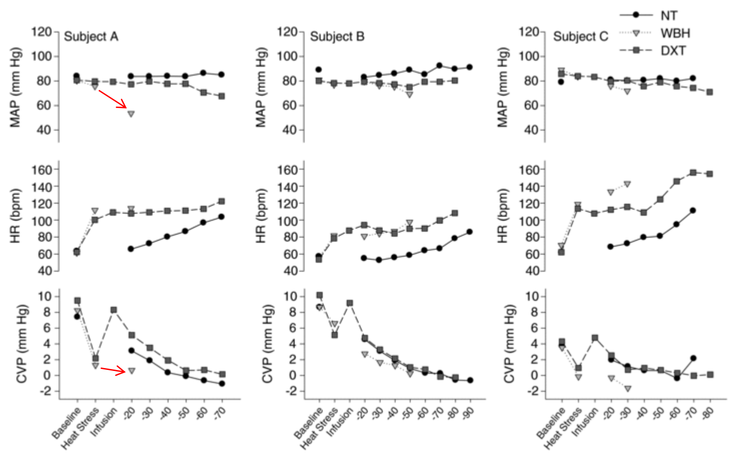
HERZKREISLAUFSYSTEM -HITZESTRESS

I = Baseline
II = Aufheizen
III = Dekompensation



ACUTE VOLUME EXPANSION PRESERVES ORTHOSTATIC TOLERANCE DURING WHOLE-BODY HEAT STRESS IN HUMANS

Keller DM et al. J Physiol 2009; 587:1131-1139



n = 7
mean age = 40±10 years)
heat stress: T_{core} increase by 1.5º C

TEST TERMINATION CRITERIA:

feeling faint, feeling like she/he could no longer tolerate LBNP, pallor, diaphoresis, RRsys < 70mmHg; bradycardia

MAP 89mmHg HF 89/Min
ZVD 12 mmHg

AUFNAHME AUF INTENSIVSTATION

MAP 76mmHg HF 85/Min
ZVD 12 mmHg

1,5 STUNDEN NACH AUFNAHME
NITROPERFUSOR + WARMLUFTGEBLÄSE
1 l Kolloid + 1,5 l Kristalloid

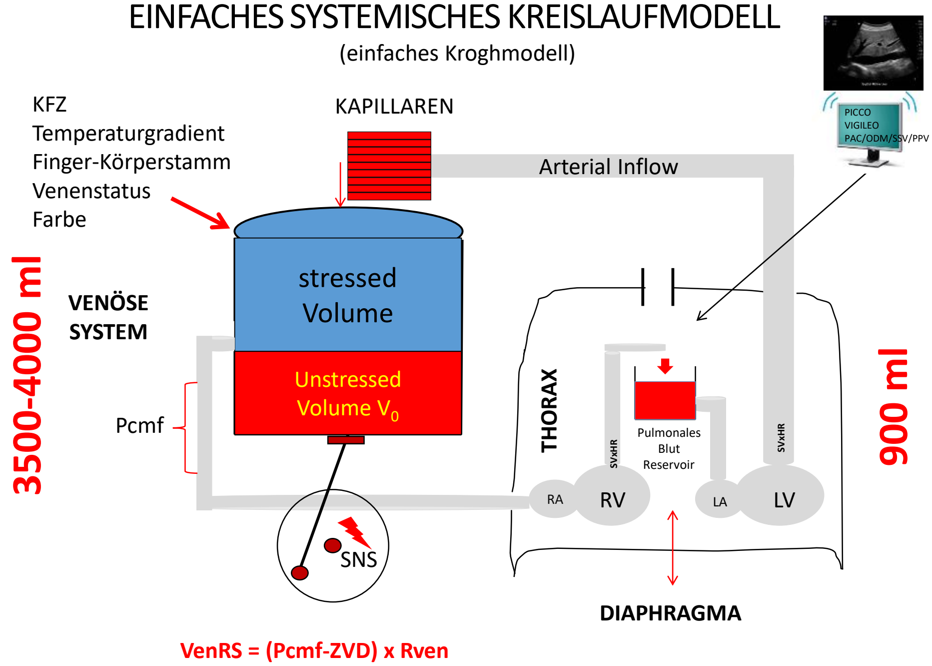
Intraop.
RIS, Warmluftgebläse
Zellsaver

Kerntemp. ≈ 37° C

18a postop. nach lap. Splenektomie

EINFACHES SYSTEMISCHES KREISLAUFMODELL

(einfaches Kroghmodell)



Changes in peripheral perfusion relate to visceral organ perfusion in early septic shock: A pilot study

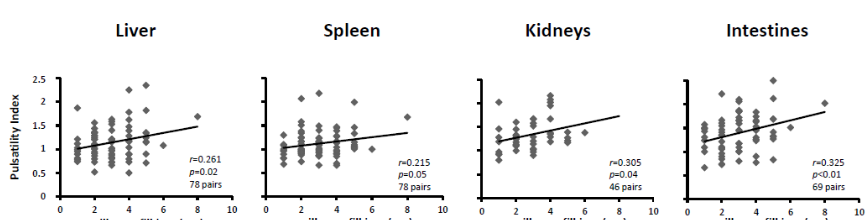
Brunauer A et al.
J Crit Care 2016; 35:105-109

30ptt in septic shock

CRT, mottling score, peripherial temperature Pulsatility index liver, spleen, kidney, intestine

Comparison of Survivors and non-Survivors

Parameter	ICU survivors	ICU non-Survivors	*p*-value
Pulsatility indices			
liver	1.12±0.52	1.25±0.49	0.25
spleen	1.07±0.22	1.41±0.46	0.03*
kidneys	1.32±0.35	1.41±0.14	0.53§
intestines	1.34±0.37	1.63±0.42	0.02*
Markers of peripheral perfusion			
capillary refill time (sec)	2.8±1.2	4.2±1.7	0.02*
Mottling Score (pts)	0.1±0.5	1.3±1.5	0.02*
any degree of skin mottling (%)	8.6	58.3	<0.001*
cold periphery (%)	34	75	0.01*
Markers of tissue metabolism			
central venous oxygen saturation (%)	72±8	72±11	0.88
arterial lactate level (mmol/L)	2±2.1	5.1±4.3	0.03*
base deficit (mmol/L)	1.4±5.6	-5.8±6	<0.001*
Organ function			
hourly diuresis (mL)	49±68	10±15	<0.001*
maximum SOFA score (pts)	13.2±3	15.4±3.6	0.02*



Capillary Refill Time as Part of an Early Warning Score for Rapid Response Team Activation is an Independent Predictor of Outcomes
Sebat Ch. et al. Resuscitation 2020; doi: 10.1016/j.resiscitation.2020.05.044

Early Warning Score – „10 Signs of Vitality“
New or severe Pain
Hyperthermia/Fever > 38° C
Heart Rate < 50 or > 100 bpm
Altered Mental Status, i.e. presence of new agitation, anxiety, apathy, lethargy, stupor, coma
Hypothermia < 36° C
Respiratory Rate < 6 or > 20 pMin
Systolic BP < 90 or MAP < 60 mmHg
SaO_2 < 90% and/or increasing FIO_2 requirement
Urine Output < 100ml/4hr or <30ml/h; excluding renal failure CKD 5
Capillary Refill > 3 seconds
Base Deficit ≥ 5 or Lactic Acid > 2 mmol/l

Capillary Refill Time as Part of an Early Warning Score for Rapid Response Team Activation is an Independent Predictor of Outcomes
Sebat Ch. et al. Resuscitation 2020; doi: 10.1016/j.resiscitation.2020.05.044

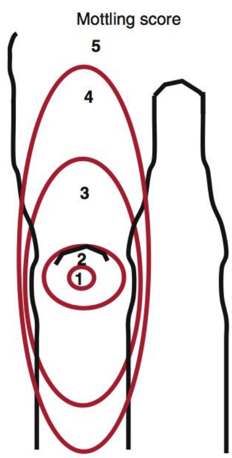
Univariat odds ratio for mortality of each of 11 parameters in the 10-SOV EWS

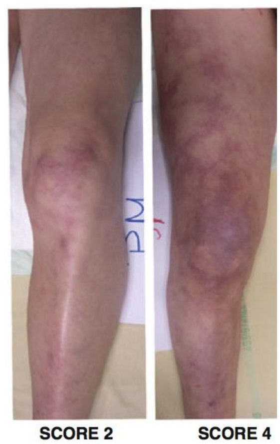
	Deaths/#Patients with Risk Factor	**Deaths/#Patients without Risk Faktor**	**Odds Ratio**	**C.I.**	**P-value**
CRT > 3 Sec	478/1329 (36%)	917/5151 (18%)	2,69	2,27-2,96	< 0,001
SaO_2 < 90% and/or increasing FIO_2	675/2127 (32%)	720/4353 (17%)	2,35	2,08-2,65	< 0,001
Syst. BP < 90 or MAP < 60 mmHg	511/1714 (30%)	884/4766 (19%)	1,87	1,64-2,12	< 0,001
UO < 100ml/4h or < 30ml/h	121/396 (31%)	1232/5981 (21%)	1,87	1,54-2,28	< 0,001
Hypothermia < 36° C	121/396 (31%)	1274/6084 (21%)	1,66	1,33-2,08	< 0,001
RR < 6 or > 20 bpm	1247/5498 (23%)	148/982 (15%)	1,65	1,37-1,99	< 0,001
Altered Mental Status	970/4152 (23%)	425/2328 (18%)	1,37	1,2-1,55	< 0,001
BD ≥ 5 or Lactic Acid > 2mmol/l	70/281 (25%)	1325/6199 (21%)	1,22	0,93-1,16	0,18
Pulse < 50 or > 100/min	907/3953 (23%)	488/2527 (19%)	1,18	1,1-1,41	< 0,001
Temperature ≥ 38° C	147/803 (18%)	1248/5677 (22%)	0,8	0,68-0,96	0,02
Pain: New or Significant	185/1252 (15%)	1210/5228 (23%)	0,58	0,49-0,68	< 0,001

MOTTLING SCORE PREDICTS SURVIVAL IN SEPTIC SHOCK

Ait-Oufella H et al.

Intensive Care Med 2011;37:801-807





Prospective observational study
60 ptt in septic shock
SAPS II 59 (45-71)
SOFA 11,5 (8,5-15,5)
14 day mortality rate 45%

0 – No mottling
1 – Coin sized mottling area on the knee
2 – To the superior area of the knee cap
3 – Mottling up to the middle thigh
4 – Mottling up to the fold of the groin
5 – Severe mottling that extends beyond the the groin

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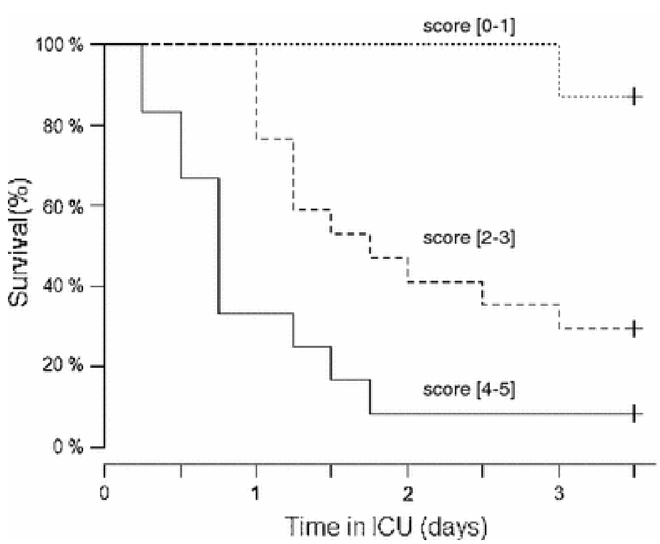

14-day survival predicted by Mottling Score