Infundabilia a tekutinová léčba

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The NEW ENGLAND JOURNAL of MEDICINE

Transfusions in Critically Ill Patients

E. W. Ely and G. R. Bernard

1999 (February 11); 340:467-468

„Umění podávat tekutiny a podporovat krevní oběh patří mezi nejdůležitější i nejobtížnější aspekty péče o pacienty v kritickém stavu.“

úvodník ke studii TRICC (Transfusion Requirements in Critical Care)

A restrictive strategy of red-cell transfusion is at least as effective as and possibly superior to a liberal transfusion strategy in critically ill patients, with the possible exception of patients with acute myocardial infarction and unstable angina.

Published in final edited form as:
J Am Soc Nephrol. 2011 December ; 22(12): 2166–2181. doi:10.1681/ASN.2011080865.

Body Fluid Dynamics: Back to the Future

Gautam Bhave[1] and **Eric G. Neilson**[1,2]

Pioneering investigations conducted over a half century ago on tonicity, transcapillary fluid exchange, and the distribution of water and solute serve as a foundation for understanding the physiology of body fluid spaces. With passage of time, however, some of these concepts have lost their connectivity to more contemporary information.

Conclusions

sejít z cesty

ukolébat, uspat

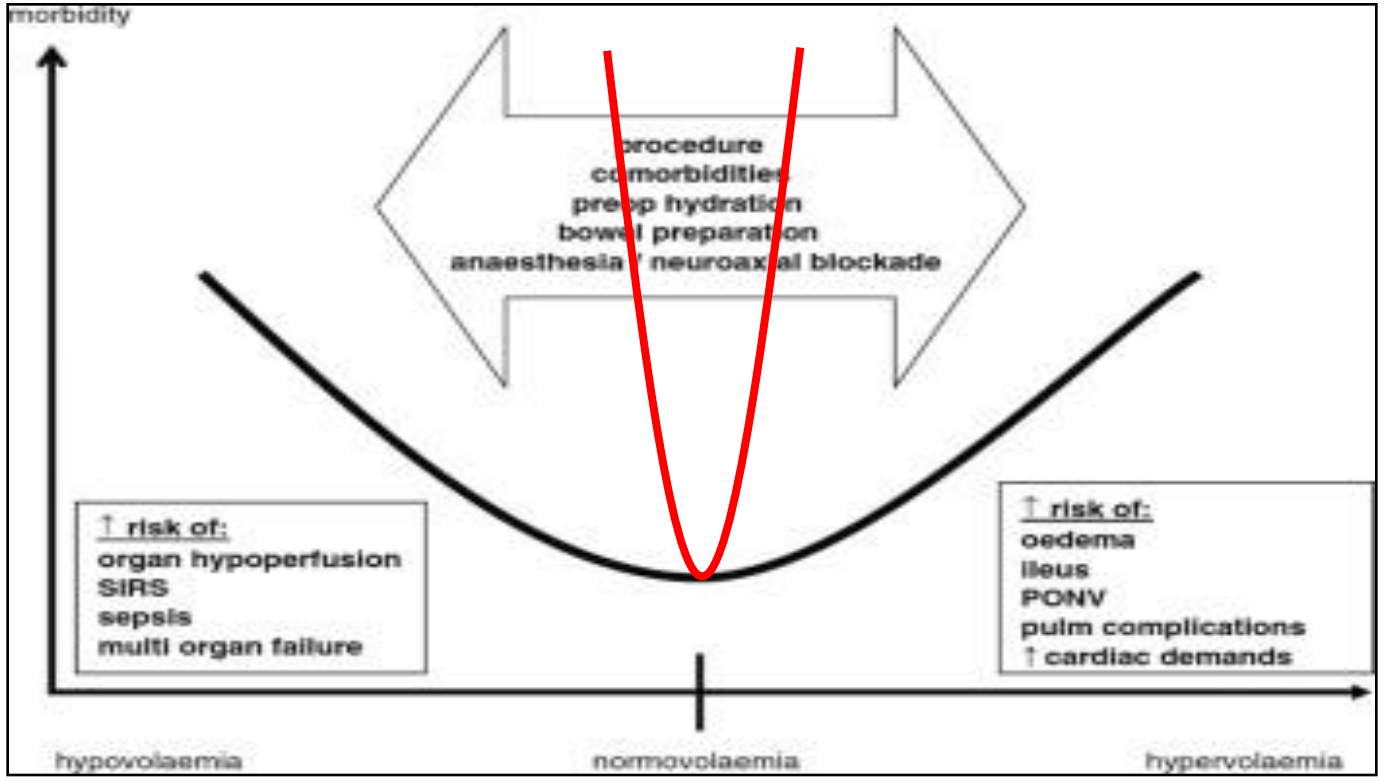
Understanding body fluid dynamics is critical to the practice of medicine. Phenomenal work accomplished during the last century has lulled us into relying on aging textbook dogma or believing there is little left to discover. Yet, re-examination of foundational literature suggests some teachings stray from original data.

Program

- Tekutiny jako léky
- Nový pohled na homeostázu tekutin
  - glykokalyx
  - revidován Starlingův model
  - intersticium již není pasivní rezervoár tekutin, nýbrž klíčový hráč v regulaci transkapilárního průtoku, zvláště pro schopnost aspirovat tekutinu z krevních cév
- Jak na podávání tekutin

Nějakou tekutinu, jakoukoliv tekutinu…prosím!

Grocott MPV, Hamilton MA: Resuscitation fluids. Vox sanquinis **2002**:82:1-8



Nebuďte příliš velkorysí při podávání tekutin!

Oh MS, Kim HJ: Basic rules of parenteral fluid therapy. Nephron **2002**:92 (suppl 1):56-59

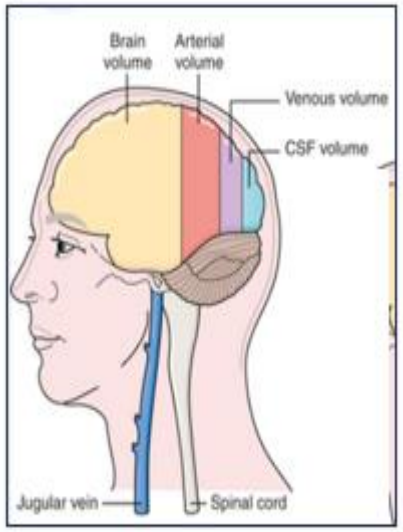
Některé mýty

- **selhávající ledviny potřebují proplachovat**

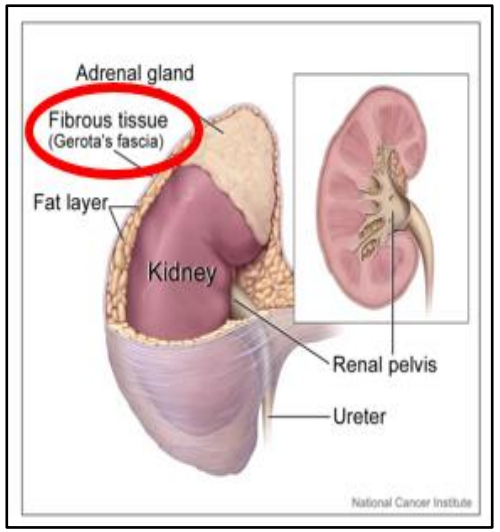
  ale **Fluid-Induced Acute Kidney Injury** (FIAKI)

  - osmotická nálož u koloidů
  - nefrotoxicita tekutin (např. vysoký obsah Cl^-)
  - edém ledviny při váznutí odtoku krve
  - k AKI může dojít i přes zvýšení průtoku krve ledvinou*

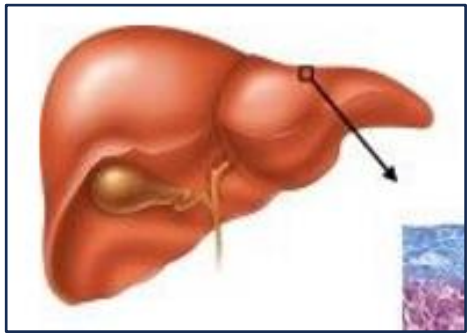
- **ledviny nabídnutou tekutinu bez problémů vyloučí** (viz dále)
- **nutná diuréza během operace 1 ml/kg/hod**
  - *ale „s diurézou si nelámej hlavu, je-li DO_2 OK a vyloučena obstrukce“*
- **tekutiny nutné k podávání léků lze u dospělého zanedbat**



Monro-Kellieova doktrina



Gerotova fascie



Glissonovo pouzdro

* Langenberg C et al.: Renal blood flow in experimental **septic** acute renal failure Kidney Int 2006; 69:1996–2002

Současný pohled na CVP

- CVP měřit, sledovat trend
- **CVP není ukazatel náplně řečiště!**
- vyšší CVP může zvýšit srdeční výdej (Frankův-Starlingův zákon)
- vyšší CVP může snížit návrat krve z orgánů (hlava, játra, ledviny) a žilní návrat

- **CVP je bezpečnostní ukazatel, jak srdce zvládá aktuální objemovou zátěž**

CAVE

edém = zduření v důsledku
akumulace tekutiny v tkáni
příčiny:

- zvýšený hydrostatický tlak
- pokles onkotického tlaku
- porušená lymfatická drenáž
- zvýšená permeabilita kapiláry

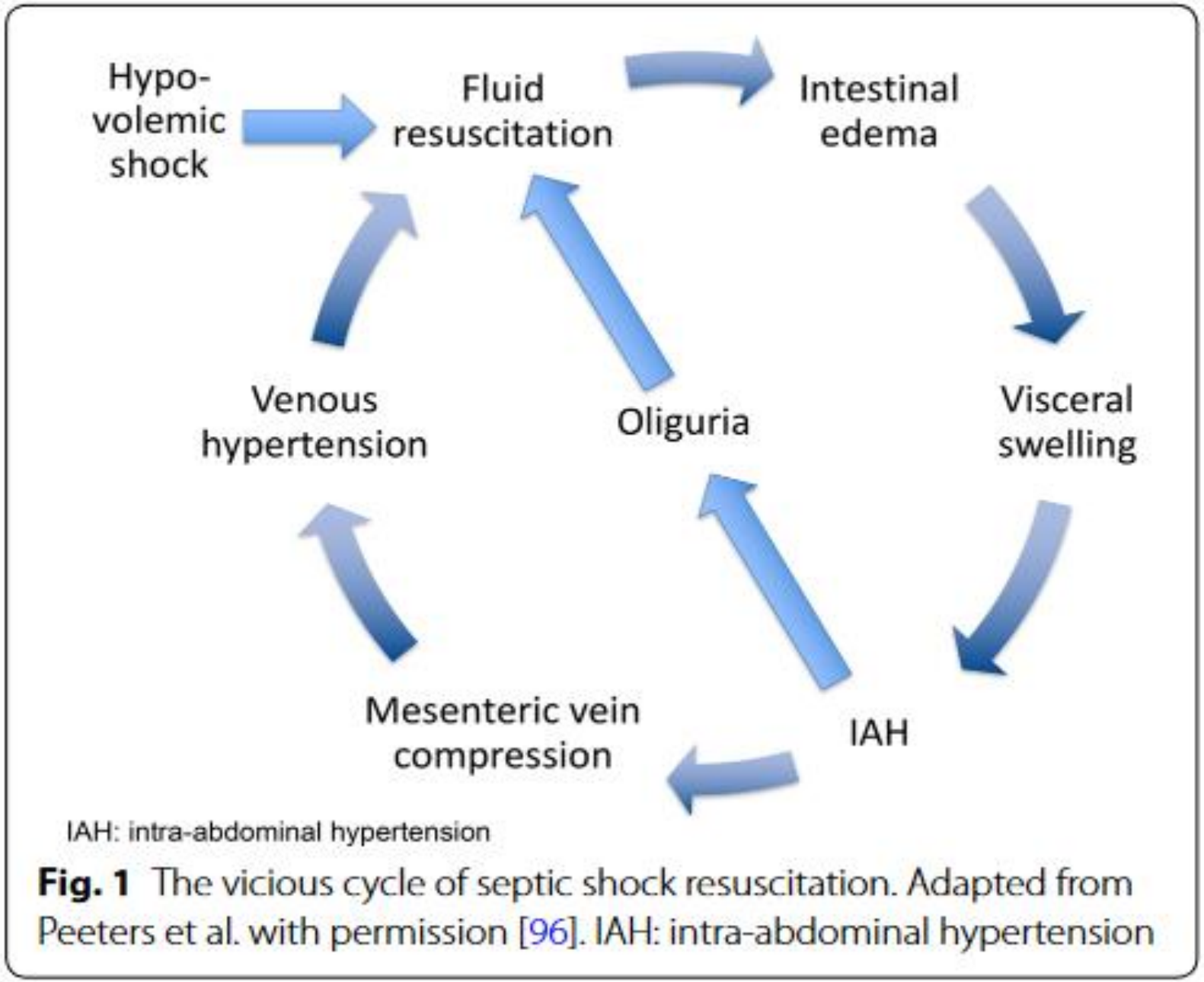


Fig. 1 The vicious cycle of septic shock resuscitation. Adapted from Peeters et al. with permission [96]. IAH: intra-abdominal hypertension

Malbrain *et al. Ann. Intensive Care (2018) 8:66*
https://doi.org/10.1186/s13613-018-0402-x

Annals of Intensive Care

REVIEW Open Access

Principles of fluid management and stewardship in septic shock: it is time to consider the four D's and the four phases of fluid therapy

Manu L. N. G. Malbrain[1,2*], Niels Van Regenmortel[3], Bernd Saugel[4], Brecht De Tavernier[3], Pieter-Jan Van Gaal[3], Olivier Joannes-Boyau[5], Jean-Louis Teboul[6], Todd W. Rice[7], Monty Mythen[8] and Xavier Monnet[6]

ORDINACE

- **D**rug = tekutina
- **D**osing
- **D**uration
- **D**e-escalation

ÚČEL TEKUTINY

- **R**esuscitation
- **R**eplacement
- **M**aintenance
- **N**utrition

- **Vehikulum** („creep“)

STADIA LÉČBY

dle IFAD

- **R**esuscitation
- **O**ptimalization
- **S**tabilization
- **E**vacuation

nebo

Dle ADQI

Salvage
Optimalization
Stabilization
De-escalation

4 indikace tekutin + vehikulum

- **maintenance** (udržovací potřeba), není-li možná enterálně,
  tj. korekce ztrát pocením, stolicí, ledvinami apod.

- **nutrition** (výživa), není-li možná enterálně

- **replacement**, není-li možný enterálně:
  - korekce deficitu vody
  - korekce deficitu iontů

- **resuscitation**, tj. doplnění kolujícího objemu krve:
  - krvácení = resuscitace oběhu (transfuze?)
  - nehemorhagický šok, např. sepse, anafylaxe

+

- nosič (vehikulum) pro podávání léků (fluid creep = vloudit se)

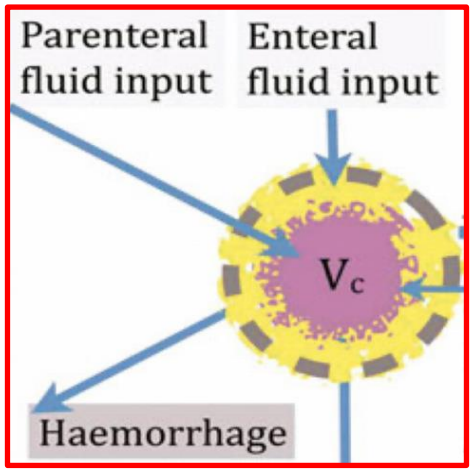
podle: Perez Nieto OR et al., Malbrain M.: Aiming for zero fluid accumulation: First, do no harm. Anaesthesiol Intensive Ther. 2021;53(2):162-178. doi: 10.5114/ait.2021.105252

Co je k dispozici pro resuscitaci oběhu?

- ✓**krystaloidy** (roztoky iontů a malých organických molekul)
  - FR = 0,9% NaCl = 9 g NaCl/l
  - Balancované
  - glukóza (čistá voda)
- **koloidy?** (disperze částic 1-1000 nm, (NÚ: alergie, ledviny, koagulace)
  - dextrany
  - želatina (20-30 kDa)
    (modifikovaná, urea-linked (Haemaccel 3,5% v FR), succinyl-l. (Gelofusin 4% v FR)
  - škrob = HES (100-1000 kDa)
    - kukuřičný
    - bramborový
  - albumin (66 kDa)
- hypertonické náhrady
- krev

částice < 50 kDa
únik ledvinami

proč koloidy působí anemii?
rozdílný distribuční prostor



Optimální strategie stále neznámá, zřejmě u různých pacientů různá.

Intravenous fluid therapy in adults in hospital

https://www.nice.org.uk/guidance/cg174/

Clinical guideline [CG174] Published: 10 December 2013 Last updated: 05 May 2017

1.3 Resuscitation

1.3.1 If patients need IV fluid resuscitation, use crystalloids that contain sodium in the range 130 to 154 mmol/l, with a bolus of 500 ml over less than 15 minutes. (For more information, see the table on composition of commonly used crystalloids on the guideline's tools and resources page.)

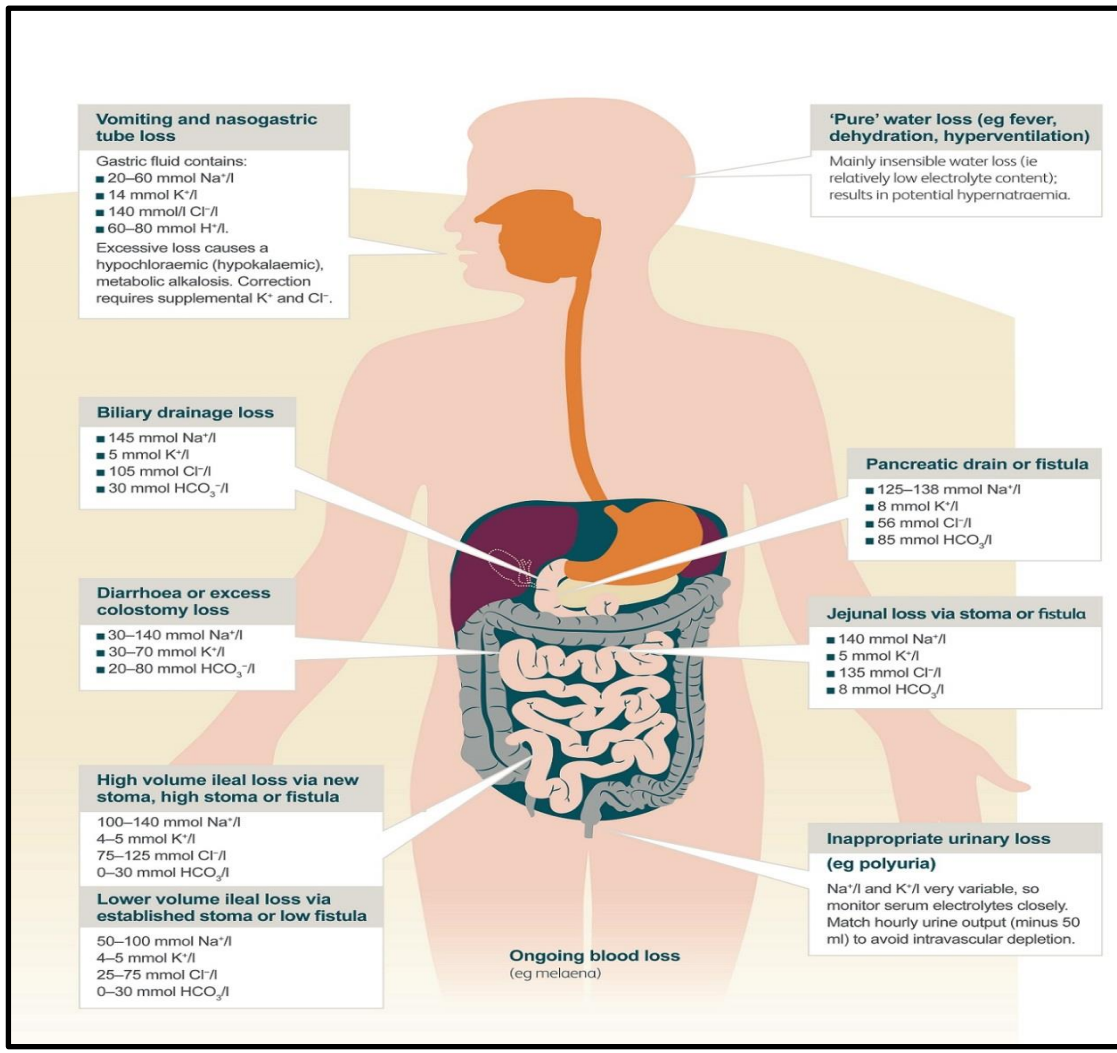
1.3.2 Do not use tetrastarch for fluid resuscitation.

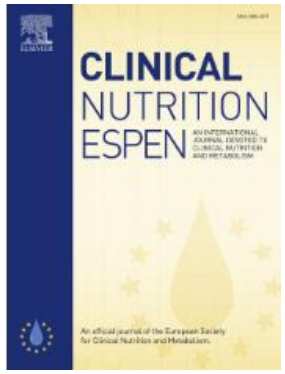
1.3.3 Consider human albumin solution 4% to 5% for fluid resuscitation only in patients with severe sepsis.

1.4 Routine maintenance

1.4.1 If patients need IV fluids for routine maintenance alone, restrict the initial prescription to:

- 25 to 30 ml/kg/day of water **and**
- approximately 1 mmol/kg/day of potassium, sodium and chloride **and**
- approximately 50 to 100 g/day of glucose to limit starvation ketosis. (This quantity will not address patients' nutritional needs; see the NICE guideline on nutrition support in adults.)





Is the NICE Guideline for maintenance fluid therapy in adults in hospital appropriate?

Clin Nutr ESPEN. 2024 Jun 19:63:113-120. doi: 10.1016/j.clnesp.2024.06.021.

NICE guidelines:

- H_2O: 25-30 ml/kg t. hm.
- Na^+: 1 mmol/kg/t. hm.
- K^+: 1 mmol/kg/t. hm.
- Cl^-: 1 mmol/kg/t. hm.
- glukóza: 50-100 g/den
  k omezení ketózy
- obézní: dle ideální hmotnosti

2 dny udržovací infuze vedly k dehydrataci:

- 1,1 l v high-sodium skupině
  (0,9% FR + 40 mmol KCl + 5% glc 25ml/kg)
- 1,7 l v low-sodium skupině
  (Glucion 5% Baxter, 54/26/55 + P, Mg, lac 25 ml/kg)

Hahn RG & van Regenmortel N:

- **H_2O: 35-40 ml/kg t. hm.**
- **Na^+: 2 mmol/kg/t. hm.**
- **K^+: 1 mmol/kg/t. hm.**

GUIDELINES

European Society of Intensive Care Medicine clinical practice guideline on fluid therapy in adult critically ill patients. Part 1: the choice of resuscitation fluids

Intensive Care Med 2024;50:813-831

Yaseen M. Arabi[1*], Emilie Belley-Cote[2], Andrea Carsetti[3], Daniel De Backer[4], Katia Donadello[5,6], Nicole P. Juffermans[7], Naomi Hammond[8,9], Jon Henrik Laake[10], Dawei Liu[11], Kathryn Maitland[12], Antonio Messina[13,14], Morten Hylander Møller[15,16], Daniele Poole[17], Rob Mac Sweeney[18], Jean-Louis Vincent[19], Fernando G. Zampieri[20] and Fayez AlShamsi[21] on behalf of European Society of Intensive Care Medicine

- ✓ přednostně krystaloidy, FR jen u TBI, albumin u cirhózy
- ✓ krystaloidy přednostně balancované, hlavně je-li třeba velký objem, je-li hyperchloremie či acidóza
- ✓ u TBI (trauma brain injury) se vyhnout hypotonickým roztokům
- ✓ isotonické krystaloidy přednost před hypertonickou resuscitací

Drug: tekutina jako lék

- krystaloid x koloid
  - fyziologický x balancovaný roztok
- aniont (bikarbonát, acetát, laktát, malát, glukonát)
- sodík
  - tonicita (hypertonický x isotonický x hypotonický)
  - dávka
    (WHO doporučená denní dávka soli 5 g = 4 v potravinách + 1 dosolení)
- chloridy (osmotický tlak, ABR, elektroneutralita)
  - vliv na acidobazickou rovnováhu
  - vliv na perfuzi ledvin
- restriktivní x liberální x goal-directed therapy

Review

Role of Crystalloids in the Perioperative Setting: From Basics to Clinical Applications and Enhanced Recovery Protocols

Table 1. Composition of plasma and the most common crystalloid solutions.

	NaCl 0.9%	Lactated Ringer's	Plasmalyte®	Isofundin®	Ionolyte®	5% Glucose	3.3% Glucose NaCl 0.9%	Benelyte®	Maintelyte®	Plasma
Na^+ (mEq/L)	154	131	140	145	137	-	154	140	40	140
K^+ (mEq/L)	-	5.4	5	4	4	-	-	4	20	4
Ca^{2+} (mEq/L)	-	2	0	2.5	0	-	-	2	-	5
Mg^{2+} (mEq/L)	-	-	1.5	1	1.5	-	-	1.5	3	2.5
Cl^- (mEq/L)	154	109	98	127	110	-	154	118	40	98
Bicarbonate (mEq/L)	-	-	-	-	-	-	-	0	23	24
Lactate (mEq/L)	-	28	-	-	-	-	-	0	-	-
Acetate (mEq/L)	-	-	27	24	34	-	-	30	23	-
Citrate (mEq/L)	-	-	-	-	-	-	-	0	-	-
Malate (mEq/L)	-	-	-	5	-	-	-	0	-	-
Gluconate (mEq/L)	-	-	23	-	-	-	-	0	-	-
Glucose (g/L)	-	-	-	-	-	50	33	10	50	-
SID in vivo (mEq/L)	0	28	50	25.5	34	0	0	-	23	42
Osmolarity (mOsm/L)	308	277	295	309	286.5	278	585	351	402	285–295

Lorente JV et al.: J. Clin. Med. **2023**, 12, 5930. https://doi.org/10.3390/jcm12185930

	plasma	FR	Ringerův laktátový r.	Ringerfundin	Plasmalyte	Isolyte	Benelyte
Na+	140	154	130	140	140	137	140
K+	4	-	5	4	5	4	4
Ca2+	2,2	-	1	2,5	-	-	1
Mg2+	1	-	1	1	1,5	1,5	1
Cl-	105	154	112	127	98	110	118
laktát	1	-	27	-	-	-	-
acetát	-	-	-	24	27	34	30
malát	-	-	-	5	-	-	-
glukonát	-	-	-	-	23	-	-
bikarbonát	22						
osmolarita	285	308	276	304	296	286	-
BE pot	-	-24	3	5	26	8	
glukóza	4,5	-	-	-	-	-	1 %
Na:Cl poměr	1,33:1	1:1	1,18:1	1,10:1	1,43:1	1,24:1	1,19:1

https://www.akutne.cz/res/publikace/9-skulec.pdf, použito dne 29.8.2021

- vazodilatace,
- ↓ kontraktility,
- rychlejší návrat do oběhu

Table 2. Characteristics of commonly available infusion fluids

	Plasma	Crystalloids				Colloids		
		0.9% NaCl	Lactated Ringer's	Plasma-Lyte	Sterofundin	Voluven (HES 6%)	Gelofusine[a]	Dextran 40
Na^+ (mmol/L)	142	154	130	140	140	154	154	154
Cl^- (mmol/L)	103	154	109	98	127	154	120	154
K^+ (mmol/L)	4.5	0	4	5	4	0	0	0
Ca^{2+} (mmol/L)	2.5	0	2.7	0	2.5	0	0	0
Mg^{2+} (mmol/L)	1.25	0	0	1.5	1	0	0	0
Buffer[b] (mmol/L)	24	0	28	50	29	0	0	0
Colloid (g/L)	35–45	0	0	0	0	60	40	100
Oncotic pressure (mmHg)	25	0	0	0	0	36	26–29	168–191
Osmolarity (mOsmol/L)	291	308	273	295	304	308	274	308
Osmolality (mOsmol/kg)	288	286	254	N/K	290	N/A	N/A	N/A

Balancované

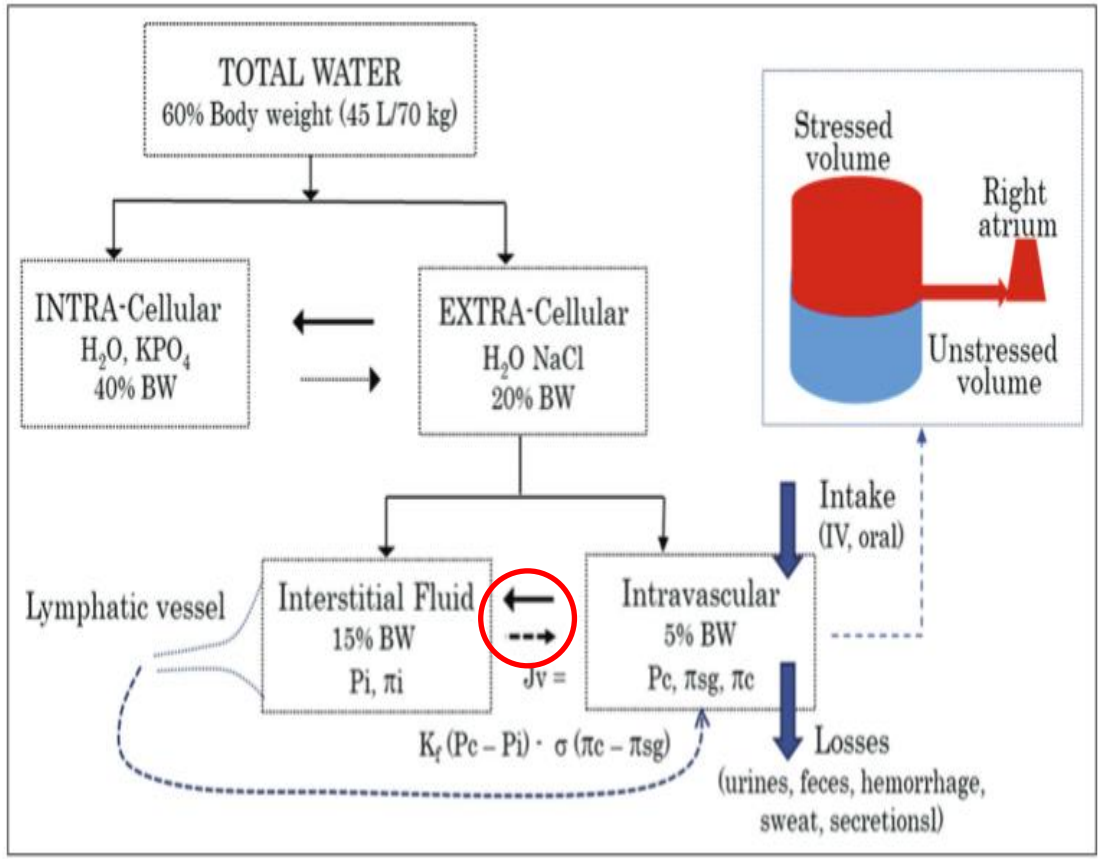
HES, hydroxyethyl starch; N/A, not applicable; N/K, not known.

[a]Contains 4% gelatin.

[b]The buffer in plasma is bicarbonate, in lactated Ringer's lactate, in Plasma-Lyte acetate (27 mmol/L) and gluconate (23 mmol/L), in Sterofundin acetate (24 mmol/L) and maleate (5 mmol/L).

Severs D et al.: A critical appraisal of intravenous fluids: from the physiological basis to clinical evidence. Nephrol Dial Transplant (2015) 30: 178–187

Fyziologie tekutin



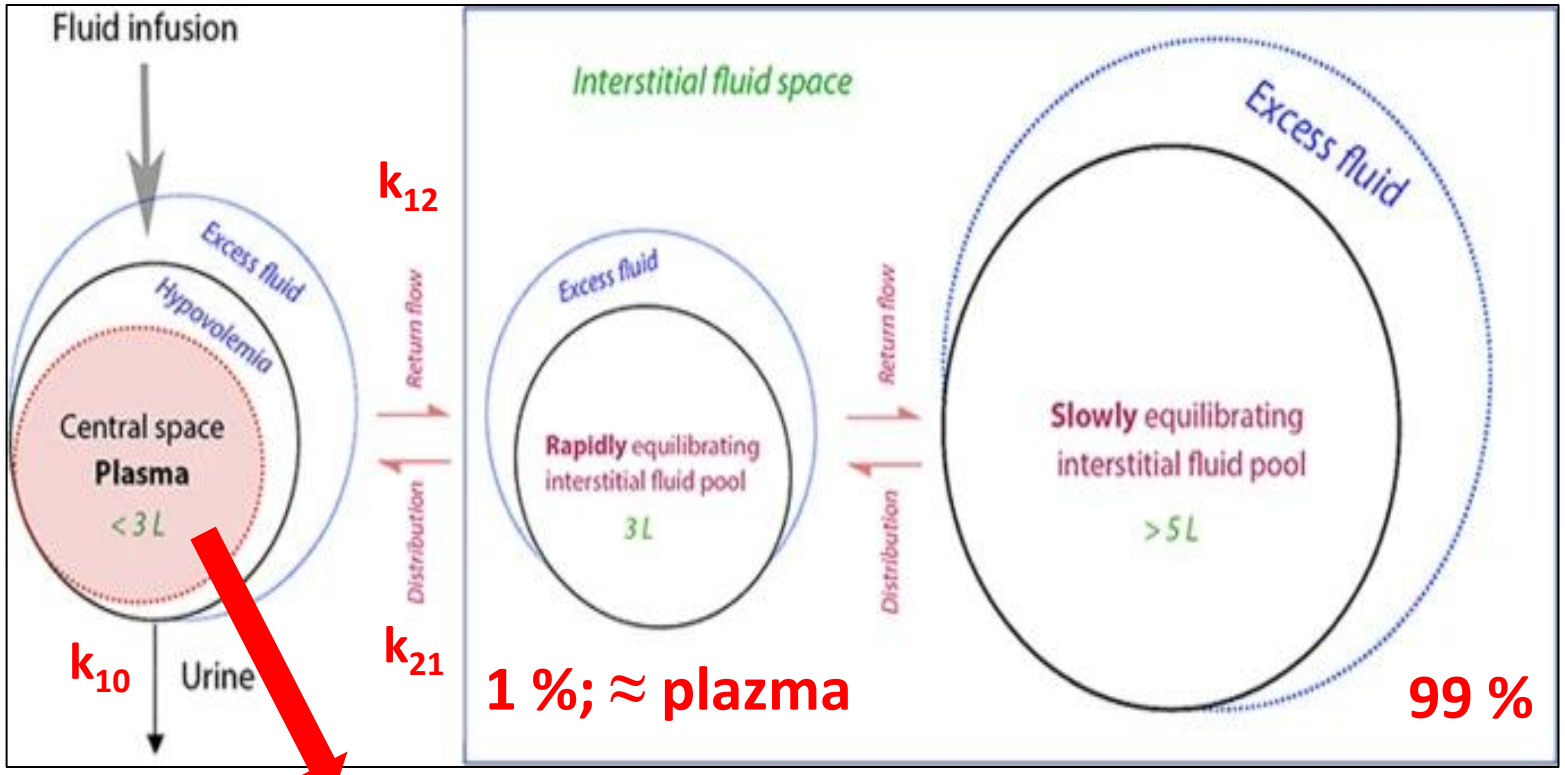
kůže 3 l tekutin, **sval 20 l tekutin** (14 l ICT+5 l IST)

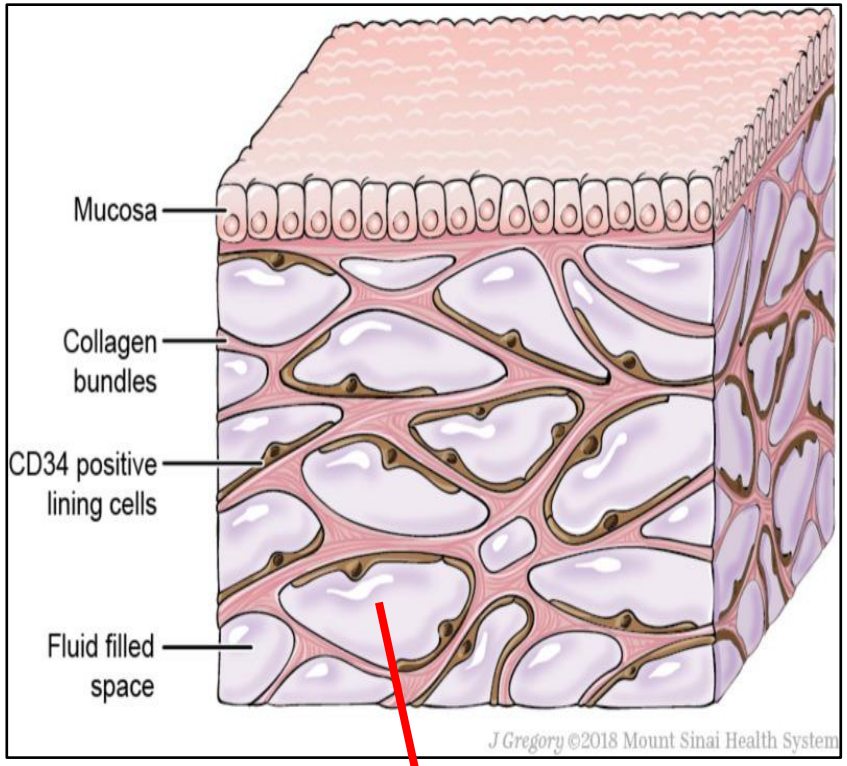
- CTV 60 % (42 l) = ICV 40 % (28 l) + ECV 20 % (14 l)
- ECV = IV 3,5 l (5 %) + IS tek. 10,5 l (15 %)
- IV kompartment = glykokalyx + free fluid
- ISF = rychlý komp. (≈ PV) + pomalý kompartment = free-fluid + gel-bound
- denní fluktuace tekutin u zdravých ≤ 0,5 %
- řízení tekutin:
  - renin-angiotenzin-aldosteron, ADH, ANP
- endotel + glykokalyx + lymfatický systém
- **Starlingův princip**
  - revidovaný (glykokalyx)
  - $t_{1/2}$ 25-30 min
- gradient pro žilní návrat (VR):
  - VR = MSFP - CVP

Licker, et al.: Perioperative fluid infusion in thoracic surgery. Saudi Journal of Anesthesia 2021, 15(33: 324-334

Fyziologie tekutin

CAVE: fragmentace matrix!





gel: hyaluronová kyselina

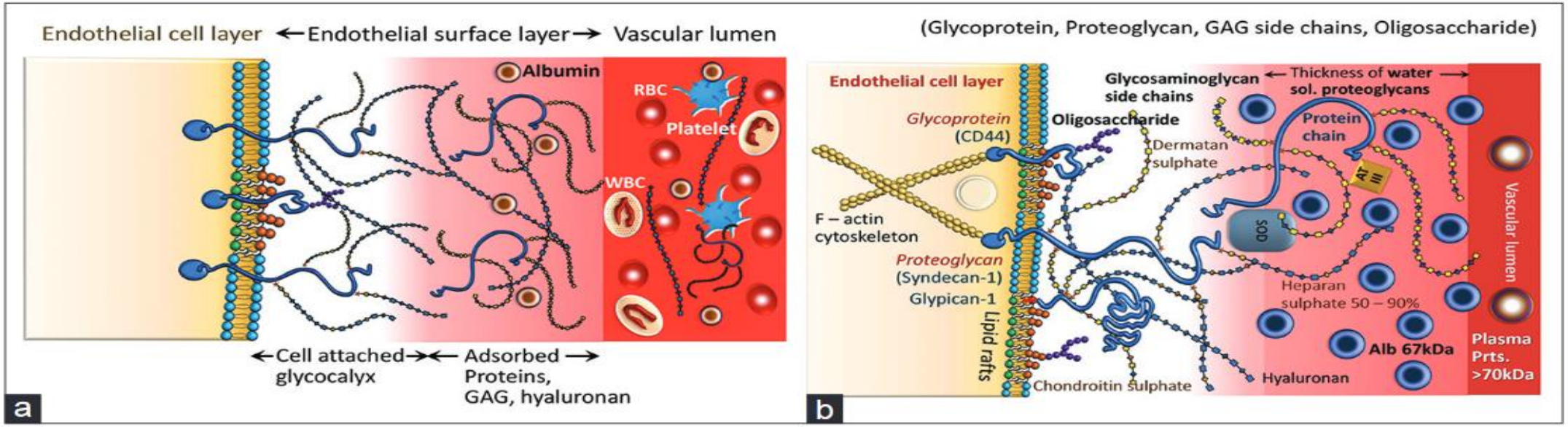
sekvestrace Na^+?

kůže, chrupavka, kost

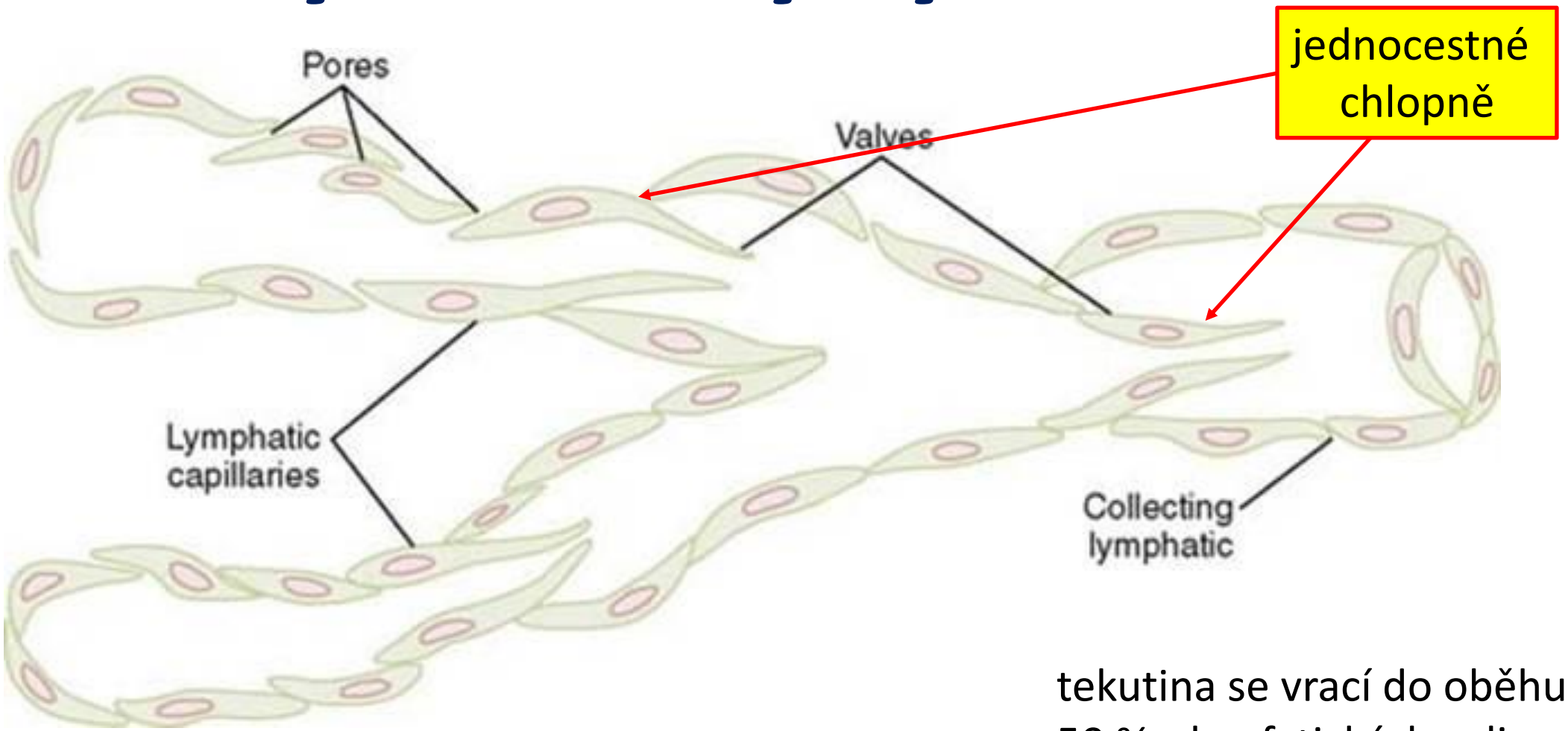
Dull RO, Hahn RG: Hypovolemia with peripheral edema: What is wrong?
Crit Care 2023 May 27;27(1):206

Glykokalyx (endothelial glycocalyx layer EGL) (endothelial surface layer ESL)

- EGL = proteoglykany + glykoproteiny + glykosaminoglykany (GAG) = mukopolysacharidy
- proteoglykany: syndekan, glypikan, mimekan, perlekan a biglykan
- GAG: heparansulfát, chondroitinsulfát, dermatansulfát, keratansulfát a hyaluronan
- solubilní složky (albumin, antitrombin, apolipoproteiny), hormony, enzymy (SOD3, ACE), růstové faktory, chemokiny a adhezní molekuly (selektiny + integriny)
- záporný náboj, **albumin 10 g/l stačí udržování glykokalyxu, permeability unit**



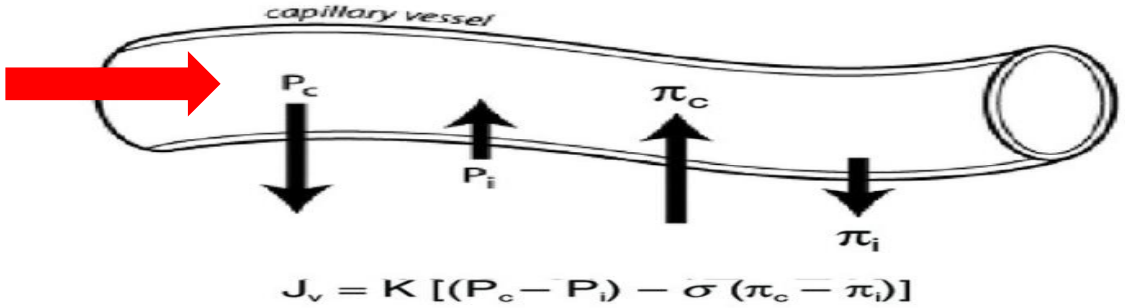
Lymfatický systém



Guyton & Hall: Medical Physiology

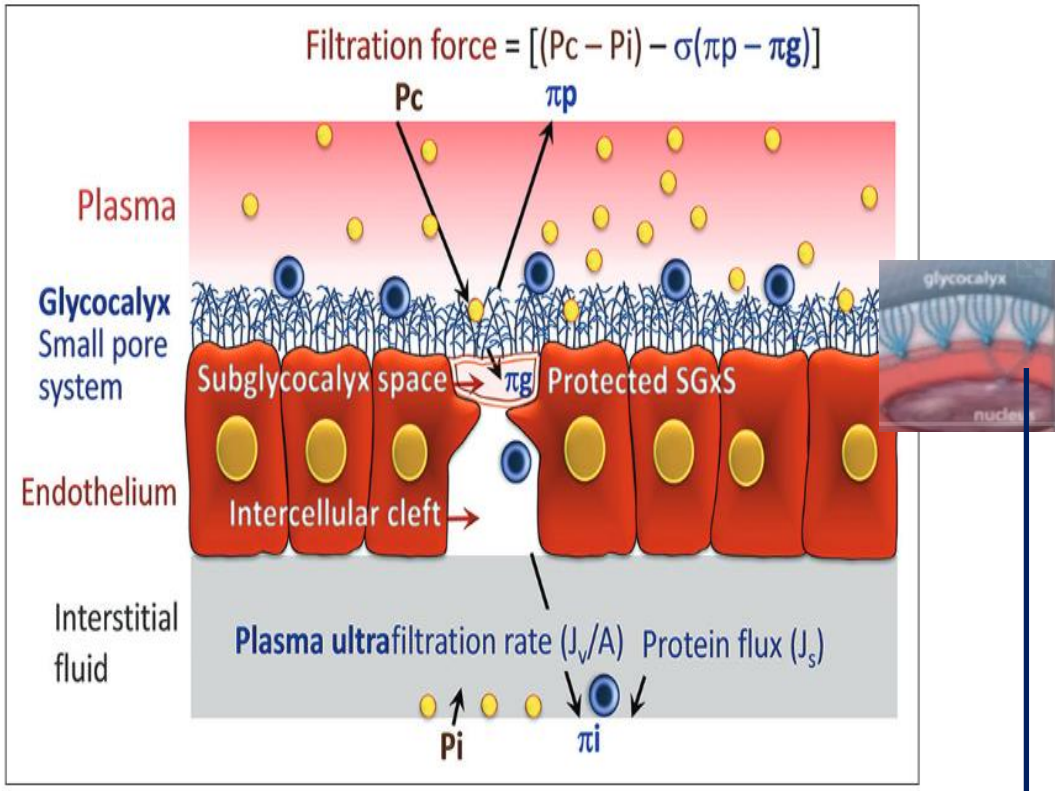
tekutina se vrací do oběhu:
50 % z lymfatických uzlin
50 % cestou ductus thoracicus

Starlingův model x rozšířený (revidovaný, one-way) model Levicka & Michela



- K = filtrační koef., σ = reflekční koef. 0,9
- P_c = art. 30, mean 17,3, ven. konec 10 mm Hg
- P_i = -3 mm Hg*
- Π_i = 8 mm Hg
- Π_c = 28 mm Hg = albumin (45 g/l) 21,8 mm Hg
  + globuliny (25 g/l) 6 mm Hg + fbg (3 g/l) 0,3 mm Hg
- Jv: A: 41 – 28 = 13 out, V: 7 in, resp. mean 0,3 → 2 ml/min

Guyton&Hall: Medical physiology, 11th ed. 2006



permeability unit

***cytokine-dependent interstitial relaxation**
P_{if} starts at − 2 to − 7 cm H_2O and become negative − 10 to − 40 cm H_2O in burns

11 nových konceptů Starlingovy rovnováhy

www.fluidphysiology.org

1. Intravascular volume = glycocalyx v + plasma v + red cell volume
2. ~~Capillaries separate plasma with high protein concentration from ISF with low protein concentration,~~ sinusoidal c. spojeny s ISF = PV
3. Starling forces are the transendothelial pressure difference and the plasma–subglycocalyx space colloid osmotic pressure difference.
4. lymph is the major route for return of extracellular fluid
5. ~~Raising plasma COP enhances absorption and shifts fluid from ISF to plasma.~~
6. ~~At subnormal capillary pressure, net absorption increases plasma volume~~

11 nových konceptů Starlingovy rovnováhy

www.fluidphysiology.org

7. ~~At supranormal capillary pressure, net filtration increases ISF volume~~, nýbrž úměrná rozdílu transendothelial pressure
8. An abrupt reduction of the transendothelial pressure difference, or an abrupt increase of the plasma–subglycocalyx space COP difference, causes a transient and limited reversal of Jv until the subglycocalyx space COP approaches plasma COP. This ‘auto transfusion’ lasts no more than 30 minutes and accounts for no more than 500ml aqueous solvent.
9. Plasma volume recovery from hypovolaemia includes both aqueous solvent and proteins, and is predominantly achieved by accelerated efferent lymph flow entering the great veins.
10. ~~nfused colloid solution is distributed through the plasma volume.~~ Infused colloid solution is distributed through the plasma volume (single compartment kinetic model).
11. ~~Infused isotonic salt solution is distributed through the extracellular volume.~~

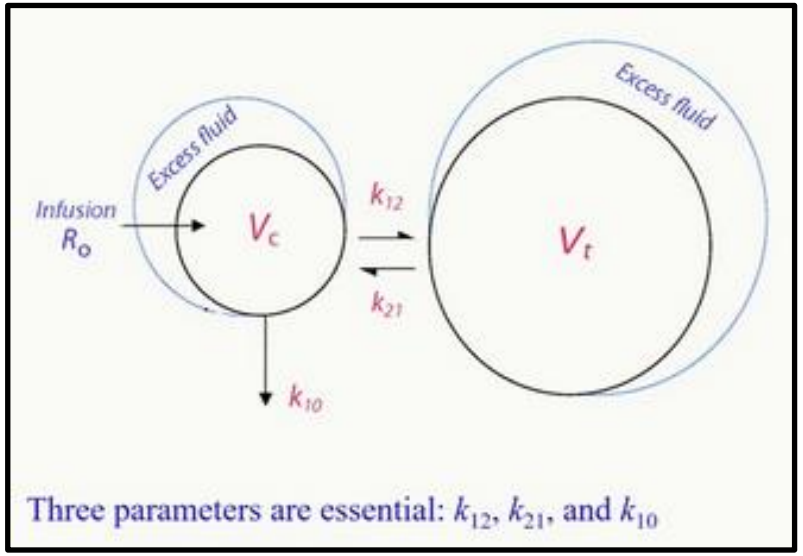
11. Infused isotonic salt solution is initially distributed through the plasma volume and glycocalyx volume and into the ISF of sinusoidal tissues (the central volume of distribution). The second volume of distribution (tissue volume of distribution) is to the expansile volume of tissues with continuous capillaries. The tissue volume of distribution for an isotonic salt solution is typically 2x the central volume of distribution, and much smaller than the total extracellular fluid volume.

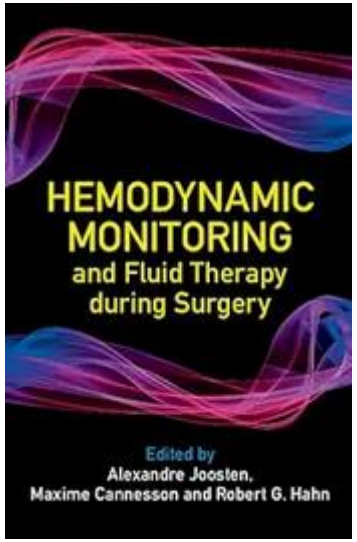
Objemová kinetika

Robert G. Hahn

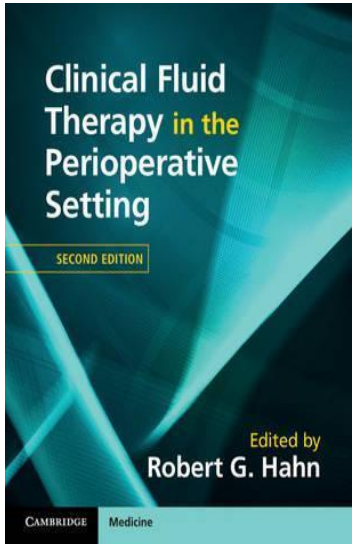
- *“fluid therapy might be more difficult than you think”*

- farmakokinetika infuzních tekutin, tj. jejich distribuce a exkrece
  - absorpce a metabolismus nehrají roli
- krev = voda (80 %) + hemoglobin
- měří opakovaně Hb a výdej moči





5/2024
65 USD



6/2016
80 USD

Objemová kinetika

- analyzuje distribuci infundovaných tekutin
- liší se:
  - u bdělých: 75-90 % objemu se vyloučí do 2 hodin
  - v anestezii: jen 5-10 %!
  - diurézu zlepší blokáda β_1-receptorů / stimulace α_1-receptorů
- Starlingova rovnováha (viz dále)
- ekvilibrace IV a IST objemu s $t_{1/2}$ 25-30 min
- návrat tekutin z IST do oběhu:
  - jen fenestrovanými kapilárami (ledviny a GIT) a lymfatickým systémem, CA lymf. systém blokuje
  - návrat pomalejší při rychlejší infuzi (> 30 ml/min = 1,8 l/hod) a naopak
  - objemový účinek při pomalejší infuzi vyšší a delší, bolusy tekutin škodí (studie FEAST)

Hahn RG: Arterial Pressure and the Rate of Elimination of Crystalloid Fluid. Anesth Analg. 2017;124(6):1824-1833

Sodík

A simplified version[19] of the equation reported by Edelman et al. is

$$\text{plasma } [Na^+] = \frac{\text{total body } (Na^+ + K^+)}{\text{total body } H_2O}.$$

- zásoba 3700-4000 mmol
  (40 % nesměnitelný díl, směnitelný díl v ICT 1000 mmol, ECT 1800-2000 mmol)

- rovnováha mezi příjmem a vylučováním Na^+, osmotická rovnováha
  - ledviny nemají aktivní mechanismus vylučování sodíku!
  - dlouhodobě vysoký příjem soli **snižuje** příjem vody (Rakova 2017)
  - rytmické kolísání zásob Na s **cirkaseptánní** a cirkalunární periodicitou beze změn t. hm., tj. **tělo udržuje stálý objem vody při různé zásobě Na^+**
- akutně zvýšená koncentrace Na^+ v plazmě
  → žízeň, zmatenost, podrážděnost, poruchy vědomí, křeče, koma

- infuze 2 l FR/25 min. dobrovolníkům vleže na zádech, exkrece 2 dny
  Drummer C: Am J Physiol 1992 May;262(5 Pt 2):F744-54.
- vyloučení Na^+ vyžaduje energii pro syntézu urey v játrech

J Clin Invest. 2017 May 1;127(5):1944-1959. doi: 10.1172/JCI88532. Epub 2017 Apr 17.

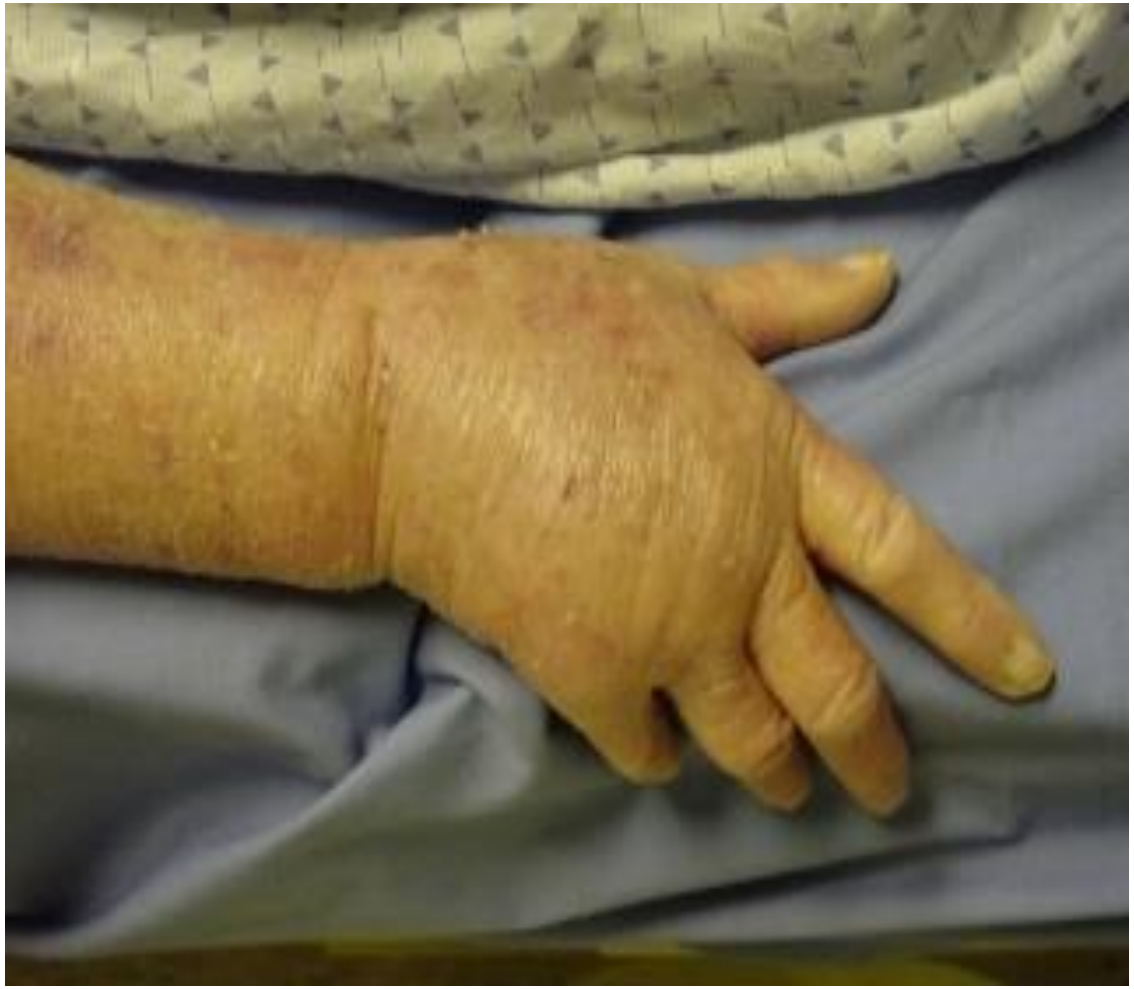
High salt intake reprioritizes osmolyte and energy metabolism for body fluid conservation

Kitada K et al.

Abstract

Natriuretic regulation of extracellular fluid volume homeostasis includes suppression of the renin-angiotensin-aldosterone system, pressure natriuresis, and reduced renal nerve activity, actions that concomitantly increase urinary Na+ excretion and lead to increased urine volume. The resulting natriuresis-driven diuretic water loss is assumed to control the extracellular volume. Here, we have demonstrated that urine concentration, and therefore regulation of water conservation, is an important control system for urine formation and extracellular volume homeostasis in mice and humans across various levels of salt intake. We observed that the renal concentration mechanism couples natriuresis with correspondent renal water reabsorption, limits natriuretic osmotic diuresis, and results in concurrent extracellular volume conservation and concentration of salt excreted into urine. This water-conserving mechanism of dietary salt excretion relies on urea transporter-driven urea recycling by the kidneys and on urea production by liver and skeletal muscle. The energy-intense nature of hepatic and extrahepatic urea osmolyte production for renal water conservation requires reprioritization of energy and substrate metabolism in liver and skeletal muscle, resulting in hepatic ketogenesis and glucocorticoid-driven muscle catabolism, which are prevented by increasing food intake. This natriuretic-ureotelic, water-conserving principle relies on metabolism-driven extracellular volume control and is regulated by concerted liver, muscle, and renal actions.

Výsledek operace a anestezie?

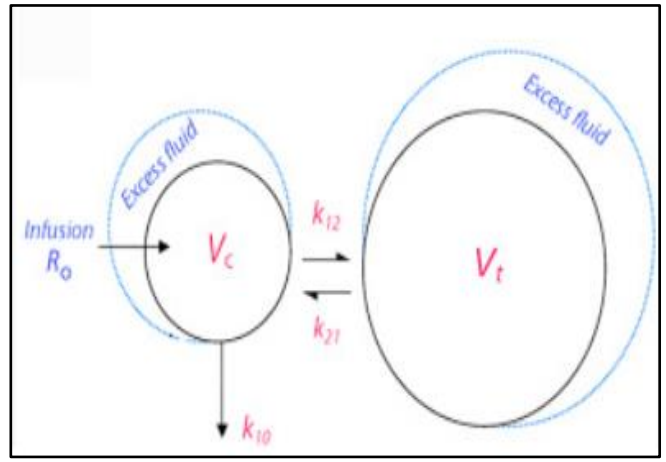


obr. © prof. V. Černý

Operace a anestezie

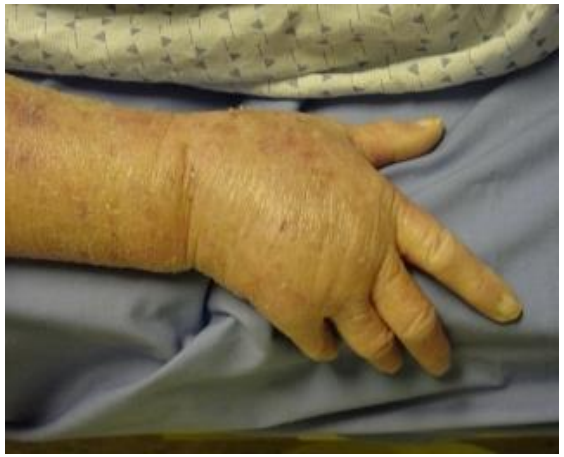
- **pro organismus stres!**
  - ***„Traumatic impulses are not excluded by ether anaesthesia from that part of the brain that is apparently asleep.“***
    George W. Crile 1909
  - látky uvolněné poškozením tkání se dostanou do mozku přes „leaky“ BBB
  - aktivace osy hypothalamus – hypofýza – nadledvina: gluko- a mineralokortikoidy (aldosteron) → retence vody (+ ADH) a Na^+, zvýšení glykemie
  - ↑ uvolňování reninu
  - aktivace sympatiku → uvolňování katecholaminů z dřeně nadledvin
- vazodilatace → „unloading“ baroreceptorů → aktivace sympatiku v ledvinách → vazokonstrikce aferentní arterioly → zvýšení resorpce vody a Na^+ → pokles GFR

Anestezie ⟶ maldistribuce tekutin a albuminu
= distribuční šok



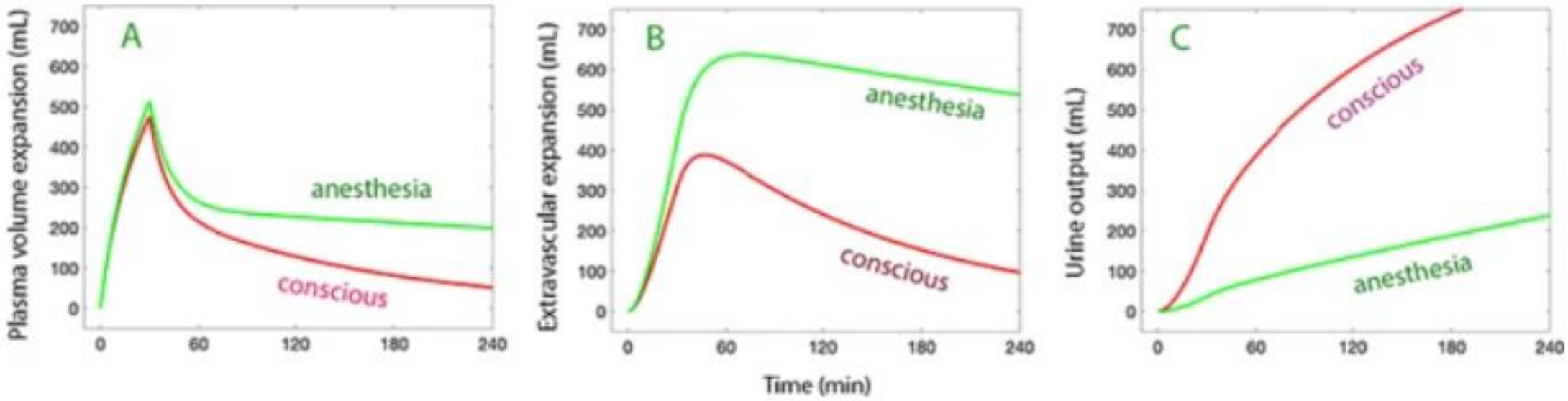
- vazodilatace (klíč. faktor, Hahn AA 2017) ⟶ zvýšení V_c
- inhibice diuretické odpovědi (k_{10}) v anestezii:
  50 % u spontánní ventilace, 90 % u UPV
- propustnost glykokalyxu ↑ (lokálně/globálně?) + snížení P_i (intersticiální tlak): k_{12}

- inhibice „lymphatic pumping“ účinkem na vnitřní i zevní síly
  celková anestetika, cytokiny, NO
- po anestezii normalizace k_{10} do 1 hod, k_{21} pomaleji
- **výsledek: hypovolemie** (maldistribuce + retence tekutin)
  + hypalbuminemie + periferní edém



Dull RO, Hahn RG: Hypovolemia with peripheral edema: What is wrong?
Crit Care 2023 May 27;27(1):206

Fig. 3 **plazma** **ECT** **moč**

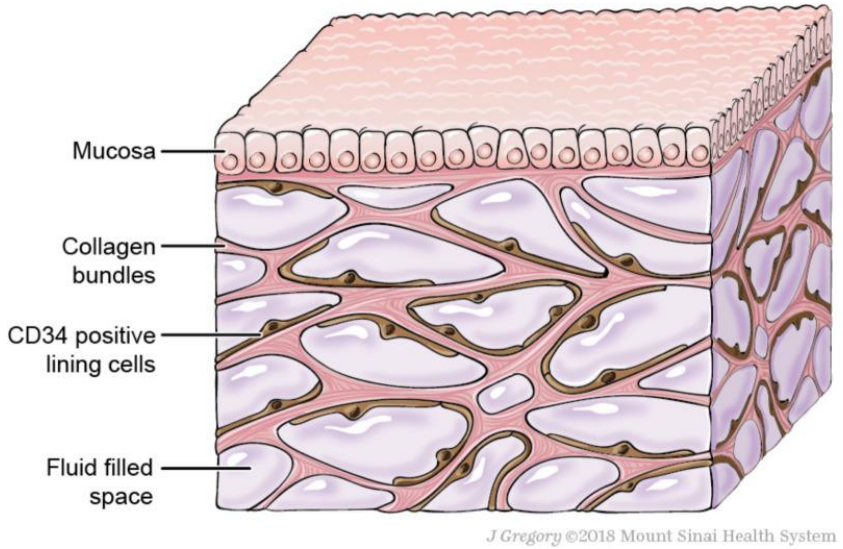


Distribution of an intravenous infusion of 15 ml/kg of buffered Ringer´s solution over 30 min followed by 10 mL/kg over 60 min between (**A**) the plasma (**B**) extravascular space, and (**C**) urine in a human weighing 65 kg (total volume 1620 mL) depending on whether he/she is conscious or under general anesthesia. Simulation based on volume kinetic parameters from 157 conscious volunteers and 85 anesthetized patients [10]. The extravascular expansion is the sum of the rapidly and the slowly equilibrating pool of fluid

Dull RO, Hahn RG: Hypovolemia with peripheral edema: What is wrong? Crit Care 2023 May 27;27(1):206

Syndrom kapilárního úniku

- hypotenze + hypalbuminemie + edémy + hemokoncentrace + paraprotein
- sekundární
  - sepse
  - ovariální hyperstimulační sy
  - autoimunita
  - APML (+ RAS, retinoic acid sy u léčby ATRA)
  - virové hemorhagické horečky
  - hadí toxiny
- primární



edém intersticia – hypoxie v důsledku ↑ interkapilární vzdálenosti - ruptury cytoskeletu

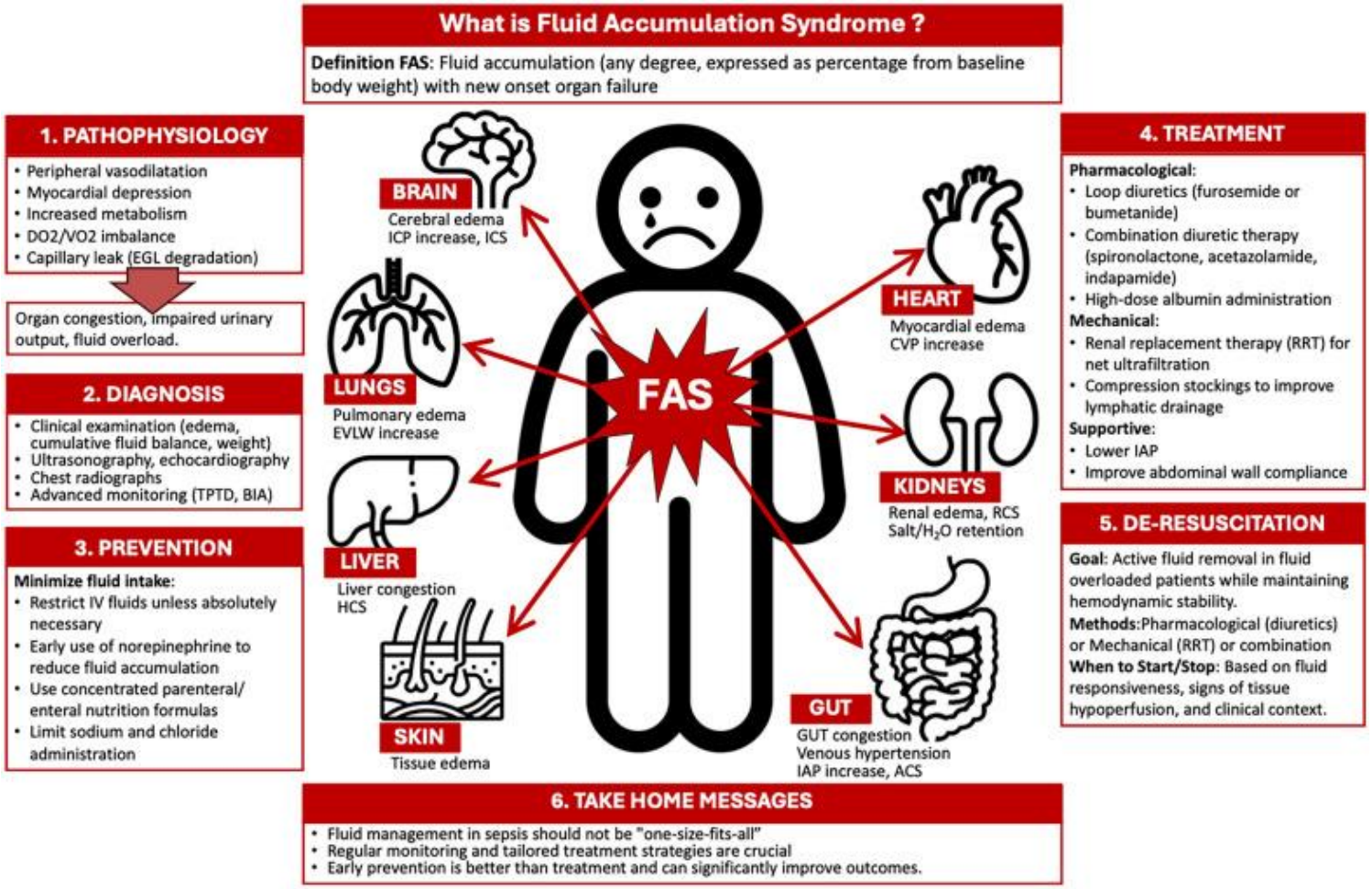
- u srdce náhlá smrt po TURP, rhabdomyolýza, kompartment syndrom

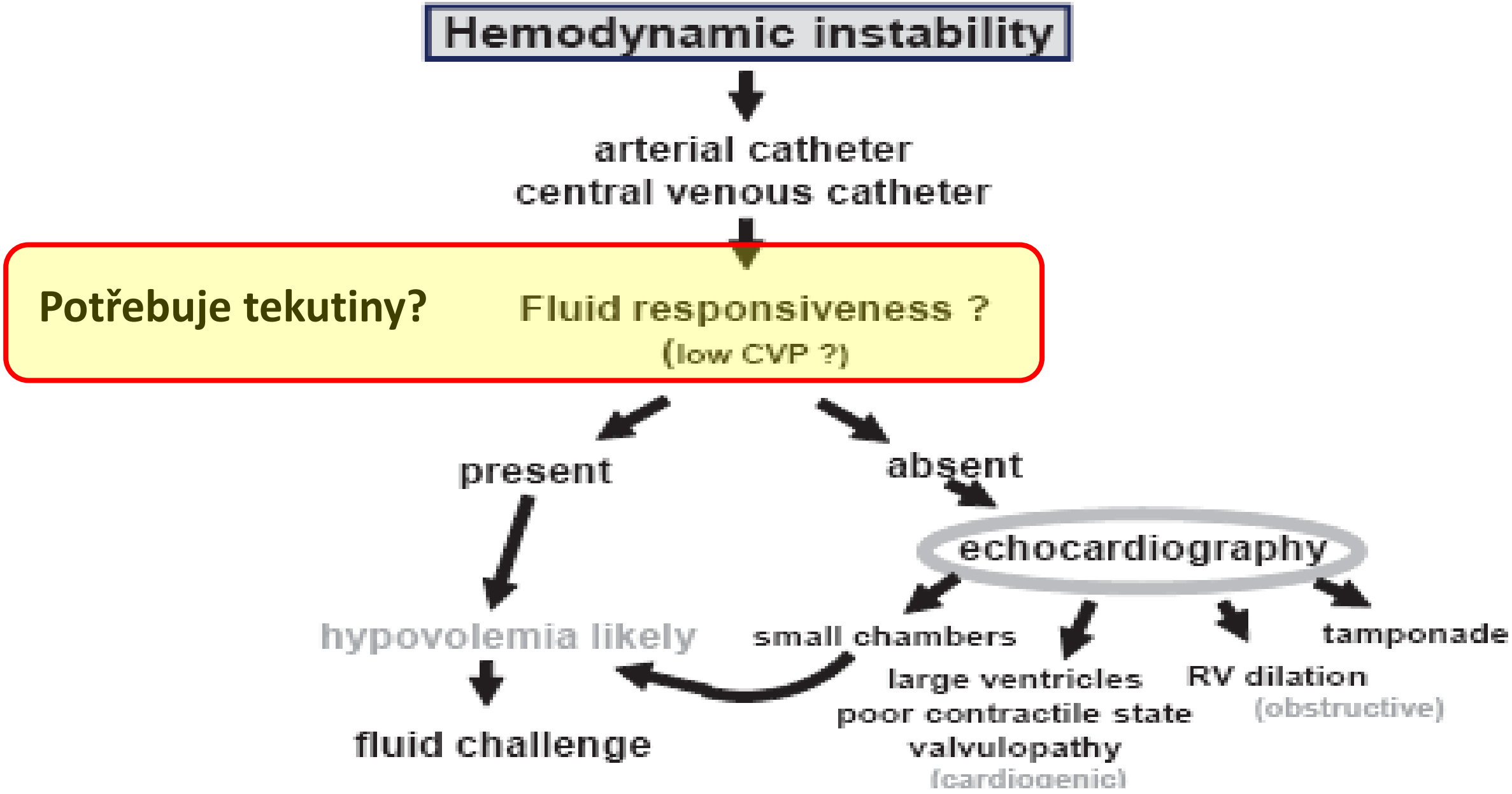
to vše může být bez zvýšení propustnosti glykokalyxu

(idiopathic systemic capillary leak syndrome (SCLS) = Clarksons´disease = spontánní periodický edém)

Mayo Clin Proc. 2010 Oct; 85(10): 905–912

Fluid accumulation syndrome





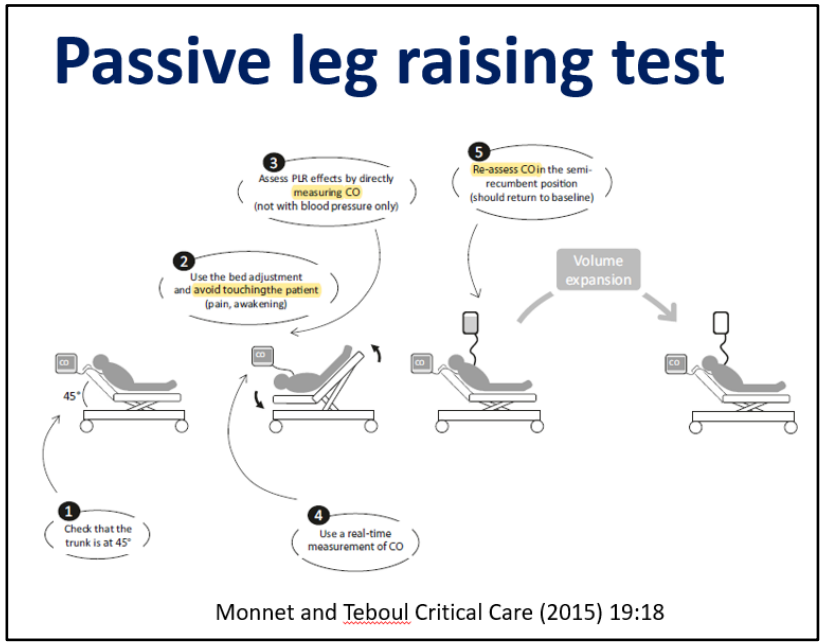
Vincent et al.: **Update on hemodynamic monitoring – a consensus of 16** *Critical Care* 2011, **15**:229, http://ccforum.com/content/15/4/229

Testování fluid responsiveness

(schopnost LK zvýšit tepový objem po podání tekutin)

klinická metoda

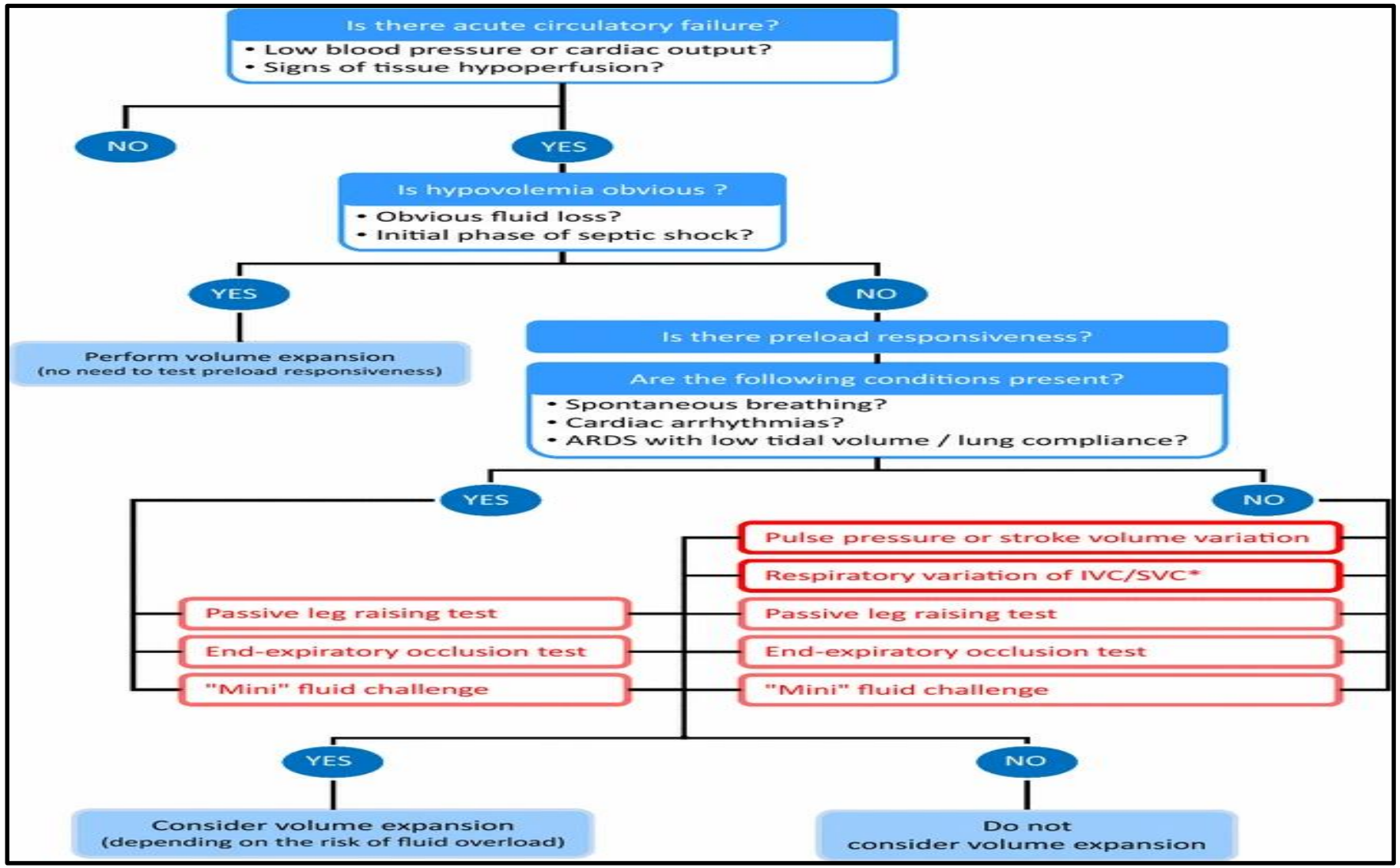
- kapilární návrat
- passive leg raising



- end-expiratory occlusion test

přístrojová metoda

- měření CO, SV
- měření kolapsibility dolní duté žíly
- puls pressure index = pulsatilní/nepulsatilní složka pletysmografie + pleth variability index
- bioimpendance



https://link.springer.com/article/10.1186/s13613-016-0216-7/figures/2

Monnet and Teboul *Ann. Intensive Care (2018) 8:54*
https://doi.org/10.1186/s13613-018-0400-z

Annals of Intensive Care

REVIEW Open Access

My patient has received fluid. How to assess its efficacy and side effects?

Xavier Monnet[1,2*] and Jean-Louis Teboul[1,2]

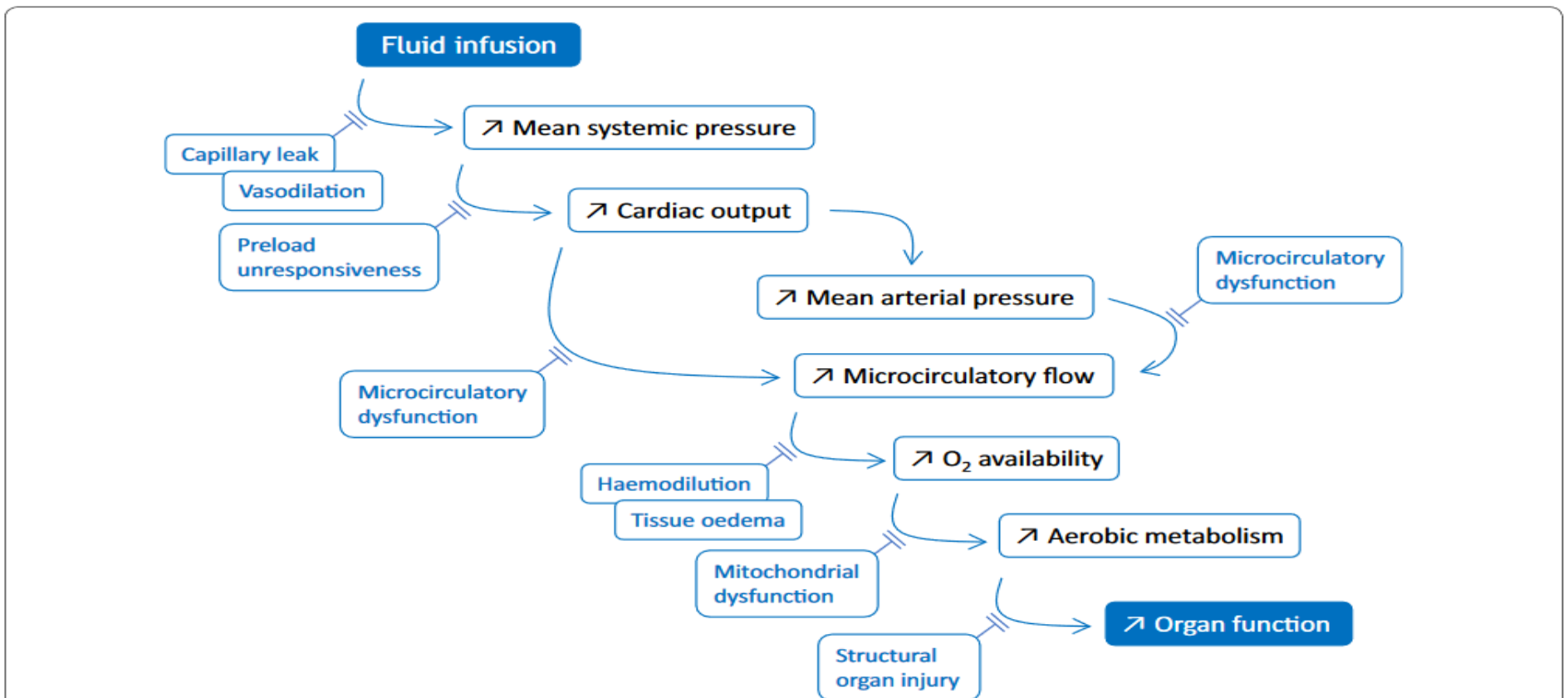


Fig. 1 Schematic pathway through which fluid administration leads to organ function improvement, and the issues that may interrupt it

Monnet and Teboul *Ann. Intensive Care (2018) 8:54*
https://doi.org/10.1186/s13613-018-0400-z

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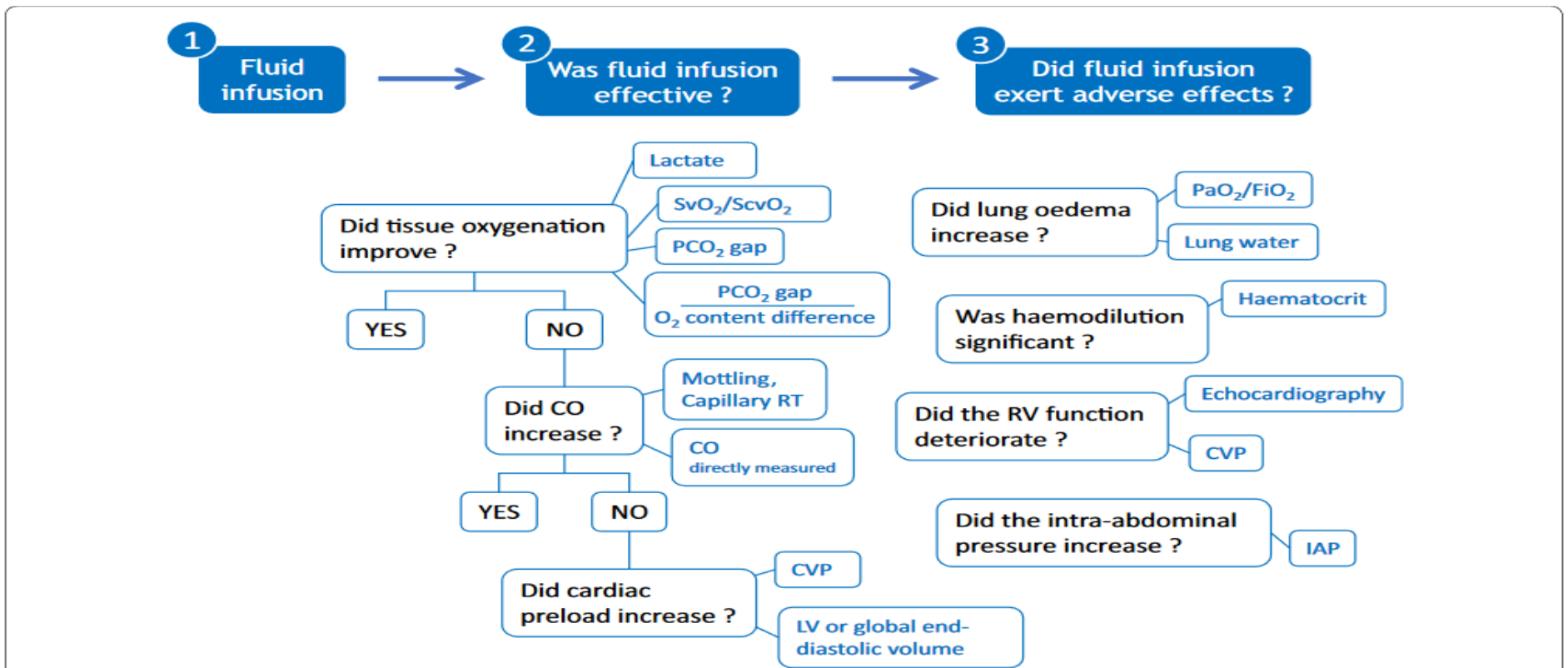


Fig. 2 Summary of the criteria on which the benefits and risks of volume expansion might be assessed. *CO* cardiac output, *CVP* central venous pressure, FiO_2 oxygen inspired fraction, *IAP* intra-abdominal pressure, *LV* left ventricular, PCO_2 carbon dioxide partial pressure, PaO_2 arterial oxygen partial pressure, *RT* refill time, $SvO_2/ScvO_2$ mixed/central venous oxygen saturation

Jednoduché shrnutí

- dilataci řečiště v CA nahradit infuzí a/nebo transcapillary refill
- **infuze ≤ 2 l přednostně balancovaných rozotků příliš neovlivňuje ABR ani jiné orgány**
- infuze > 2 mL/kg/h během operace nutná k prevenci PONV
- infuze > 3 l při operaci prodlužuje gastrointestinal recovery time
- infuze 5-6 l zvyšuje riziko špatného hojení rány, dehiscence anastomóz, městnání a edému plic
- restriktivní přístup do 5 ml/kg/h, liberální nad 7 ml/kg/hod
- odpověď na diuretika se po operaci rychle normalizuje (do 1 hodiny)

Intraoperative arterial blood pressure lability is associated with improved 30 day survival

M. A. Levin[1,*], G. W. Fischer[1,2], H.-M. Lin[1,3], P. J. McCormick[1], M. Krol[1] and D. L. Reich[1]

Brit J Anaesth 2015;115(5):716–26

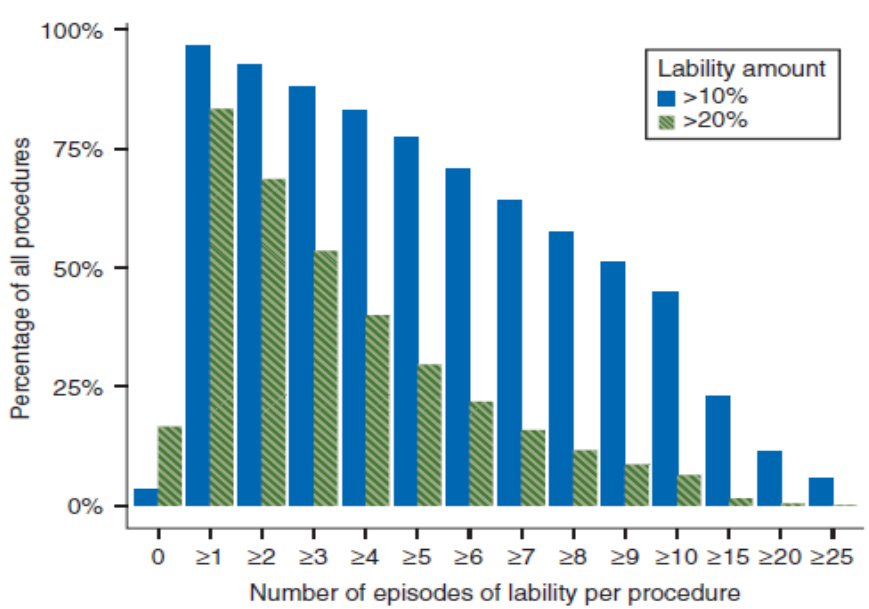


Fig 1 Frequency of intraoperative lability. Bar graph shows the number of

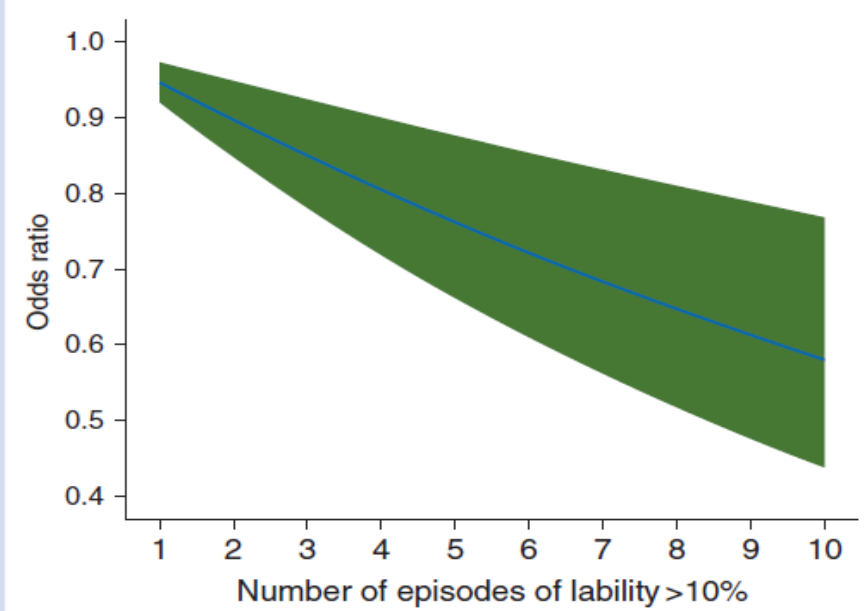
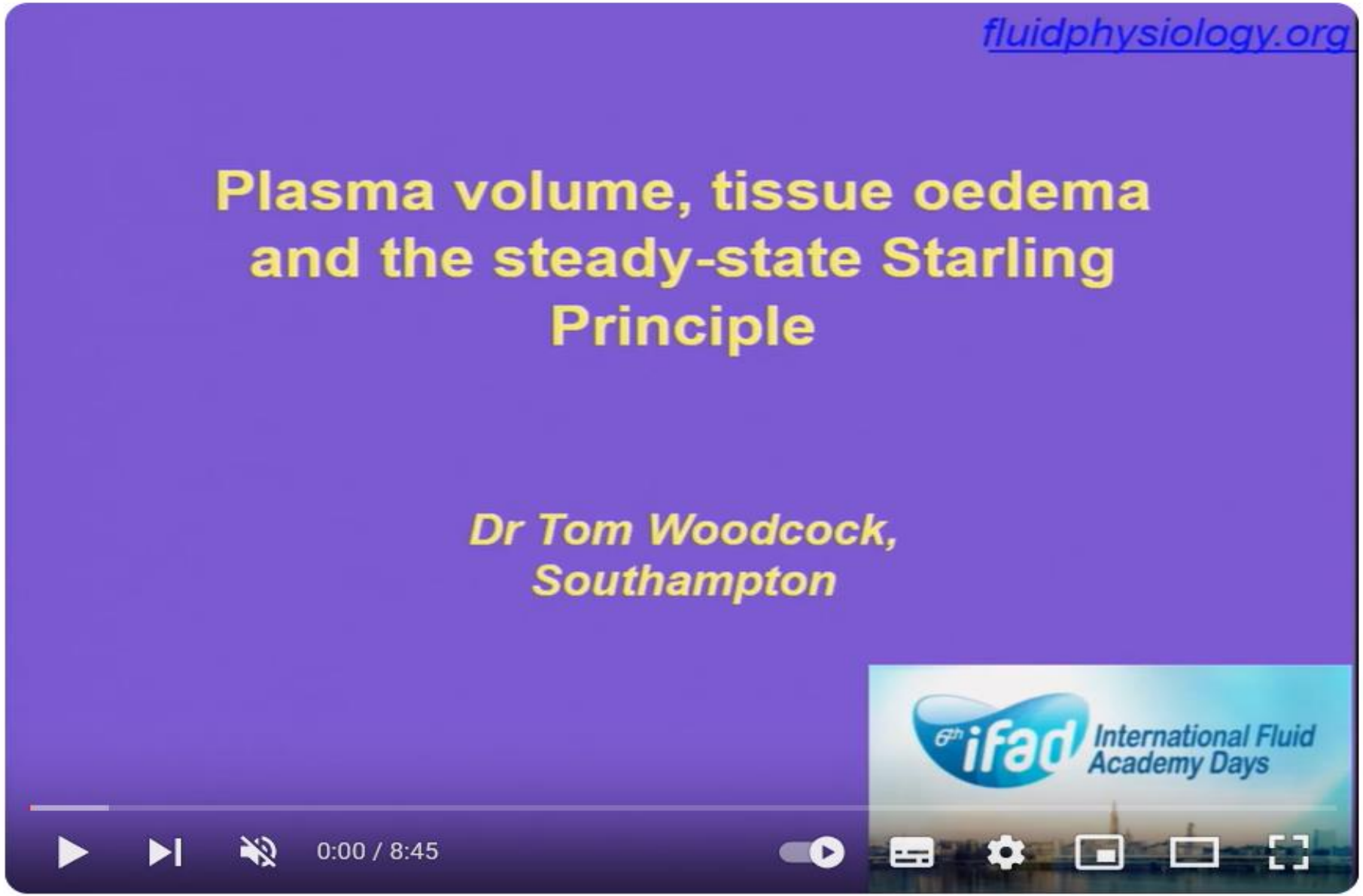


Fig 3 Association of lability with decreased 30 day mortality. Plot showing

Intraoperative arterial blood pressure lability occurs more often in hypertensive patients. **Contrary to common belief, increased lability was associated with decreased 30 day mortality**.



https://www.youtube.com/watch?v=Qm86qUPS0eI

British Journal of Anaesthesia **108** (3): 384–94 (2012)
Advance Access publication 29 January 2012 · doi:10.1093/bja/aer515

BJA

Revised Starling equation and the glycocalyx model of transvascular fluid exchange: an improved paradigm for prescribing intravenous fluid therapy

T. E. Woodcock[1]* and T. M. Woodcock[2]

[1] Critical Care Service, Southampton University Hospitals NHS Trust, Tremona Road, Southampton SO16 6YD, UK
[2] The Australian School of Advanced Medicine, Macquarie University, NSW 2109, Australia

* Corresponding author. E-mail: tom.woodcock@me.com

Editor's key points

- The classic Starling principle does not hold for fluid resuscitation in clinical settings.
- The endothelial glycocalyx layer appears to have a major role in fluid exchange.
- A revision of Starling incorporating the glycocalyx model appears to explain better the responses seen clinically.

Hypothesis

the Revised Starling Equation & Glycocalyx Model Paradigm BJA 2012.

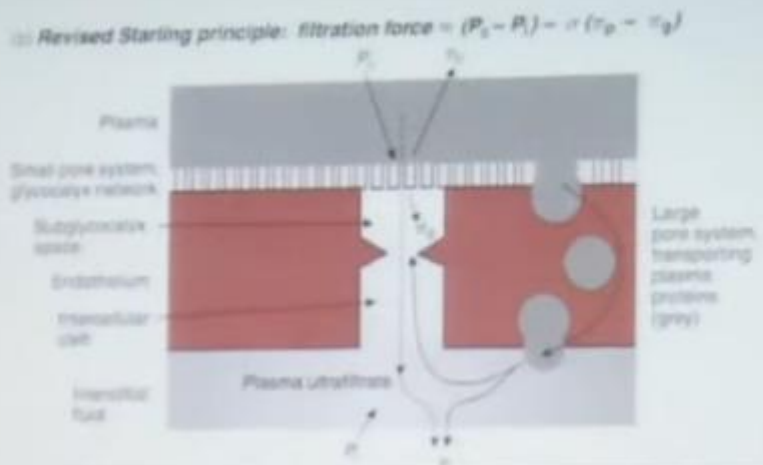
- a bolus of an isosmotic plasma substitute has a central volume of distribution which approximates the free-flowing plasma
- a bolus of an isotonic salt solution has a central volume of distribution that includes the intravascular gel phase and approximates the whole of the intravascular volume.

- The concept is supported by consistent clinical reports that adequate resuscitation with an isosmotic plasma substitute can be achieved with slightly smaller volumes than adequate resuscitation with a crystalloid, but at the expense of much diluted haematocrit.
- The ability of plasma and plasma substitutes to cause anaemia is still widely misinterpreted as indicating that the colloids are "better volume expanders".

PRACTICE POINT

Small reductions in the regional vascular resistance of a tissue bed below normal lead to substantial increases in P_{cap} and J_v.

- Precapillary vasodilators cause oedema as a side effect.
- Alpha-1 adrenergic agonists help keep P_{cap} low by precapillary arteriolar constriction.
  - They minimize delta P and therefore J_v and so are an effective anti-oedema therapy.
  - Examples include adrenaline treatment of anaphylaxis/ anaphylactoid reactions and anti-hypotensive infusions of norepinephrine or phenylephrine in anaesthetic practice.



PRACTICE POINT

- The more severe the hypovolaemia, the stronger the case for preferring crystalloid resuscitation to flush proteins from the subglycocalyx protected space and to repay the autotransfusion.
- This logic runs counter to the suggestion by some authorities that colloid solutions may be preferred in more extreme cases of hypovolaemia "because it stays in the circulation longer".
- *statim* boluses will cause transient peaks of P_{cap} that lead to transient hyperfiltration. This may account for the finding of the FEAST trial that bolus resuscitation was harmful.