Erasmus MC
Universitair Medisch Centrum Rotterdam

ICC
International Compression Club

Stiffness & edema

Prof. dr H.A Martino Neumann

Department of Dermatology, Erasmus MC

Rotterdam, The Netherlands

ICC

June 8th 2018

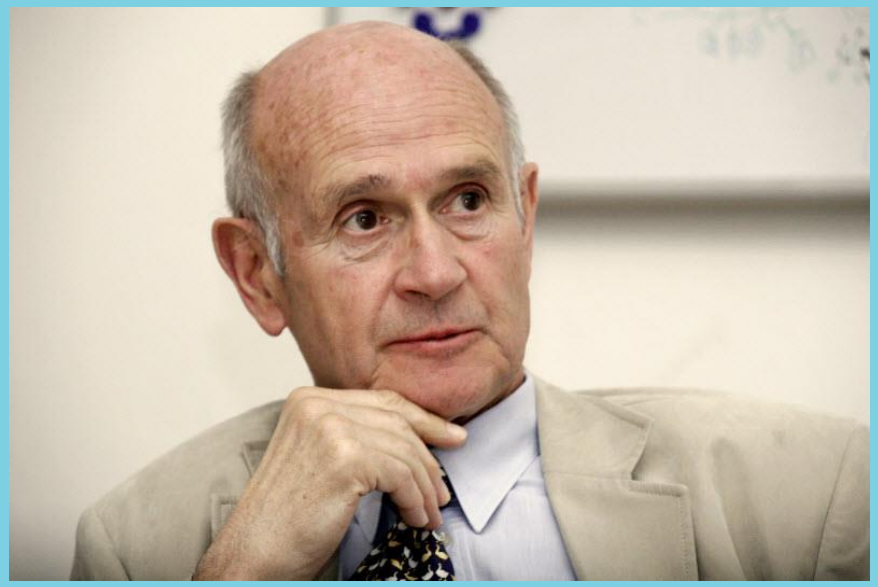
Rotterdam

Disclosure

No conflicts of interest

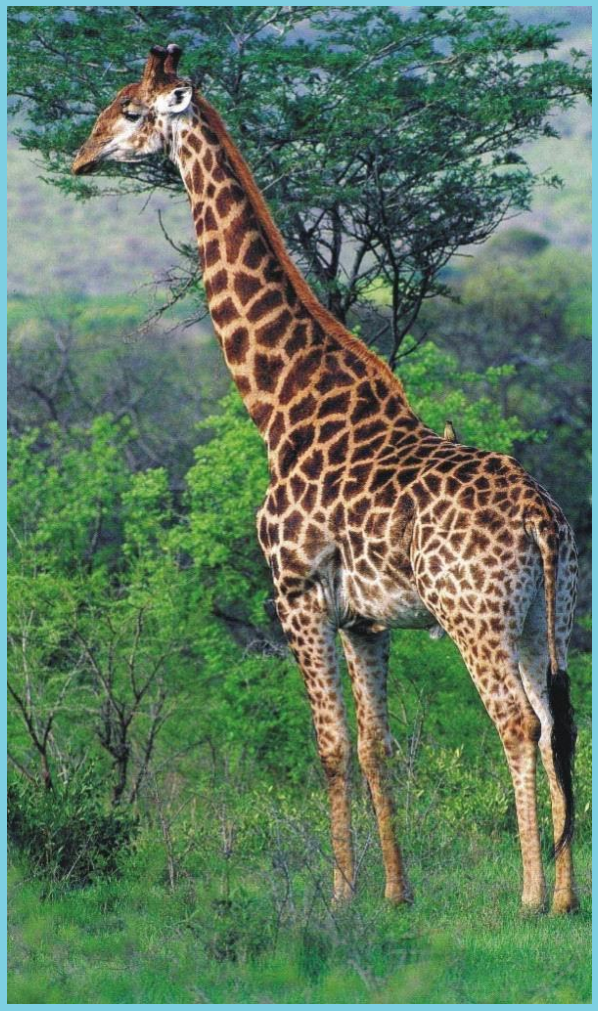
Edema

- Many courses
  - Cardiac: decompensation
  - Renal failure
  - Hypoproteinemia
  - Inflammation
  - Infection
  - Dependency
  - Lymphatic
  - etc



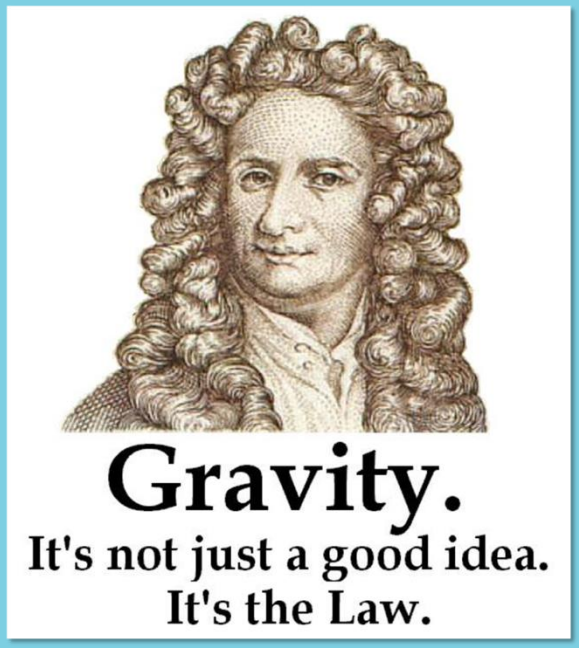
The human factor

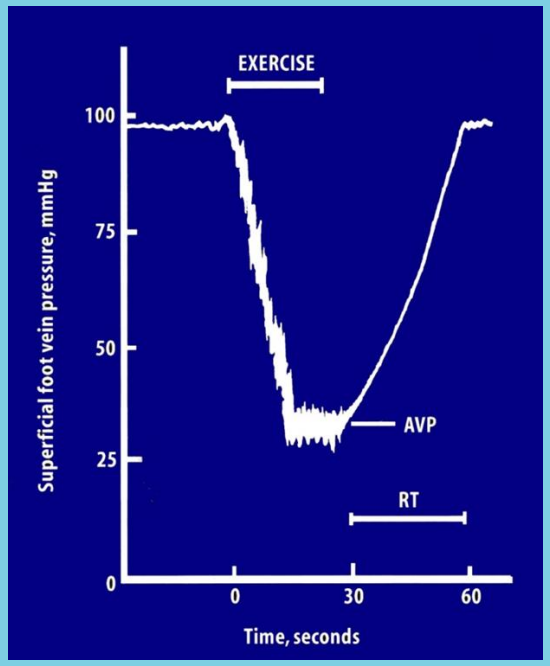
- **The Skin**



Venous edema as example

- Venous edema = venous decompensation





From vein to skin

Macro-circulation

GSV / SSV / deep veins

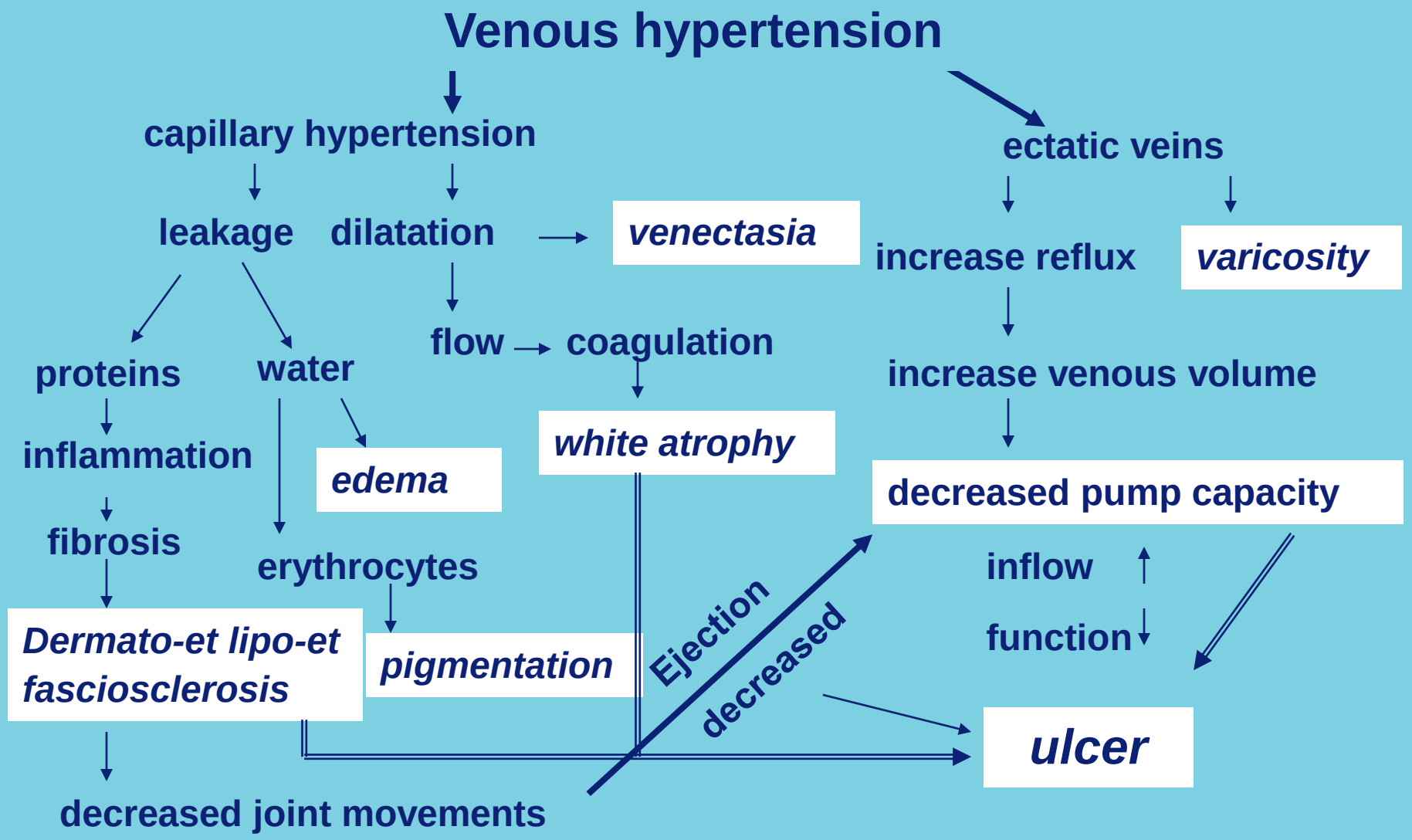
↓

Micro-circulation

↓

Skin

Rotterdam model



Cardiovascular Research (2010) 87, 198–210

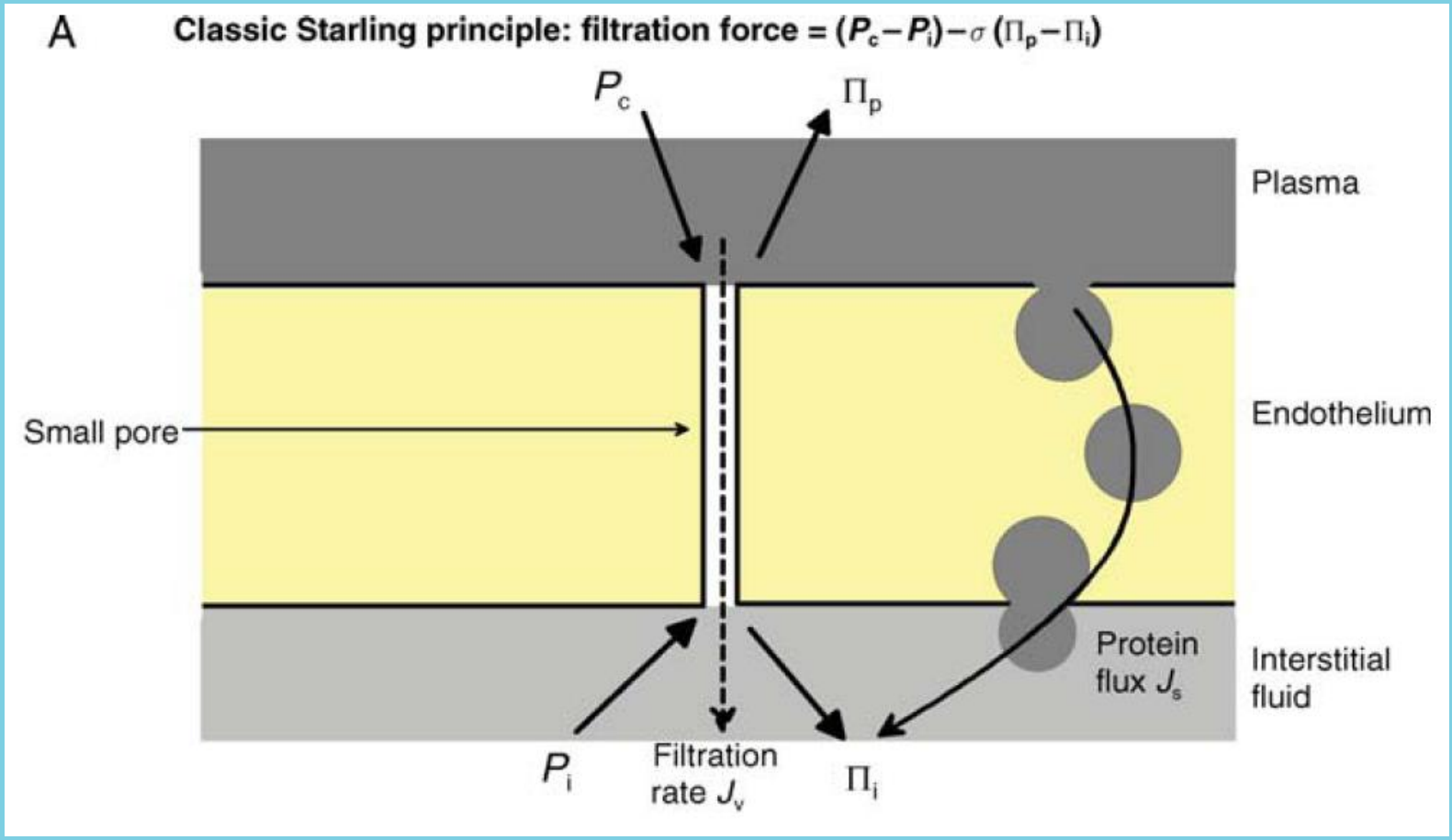
SPOTLIGHT REVIEW
Microvascular fluid exchange and the revised Starling principle

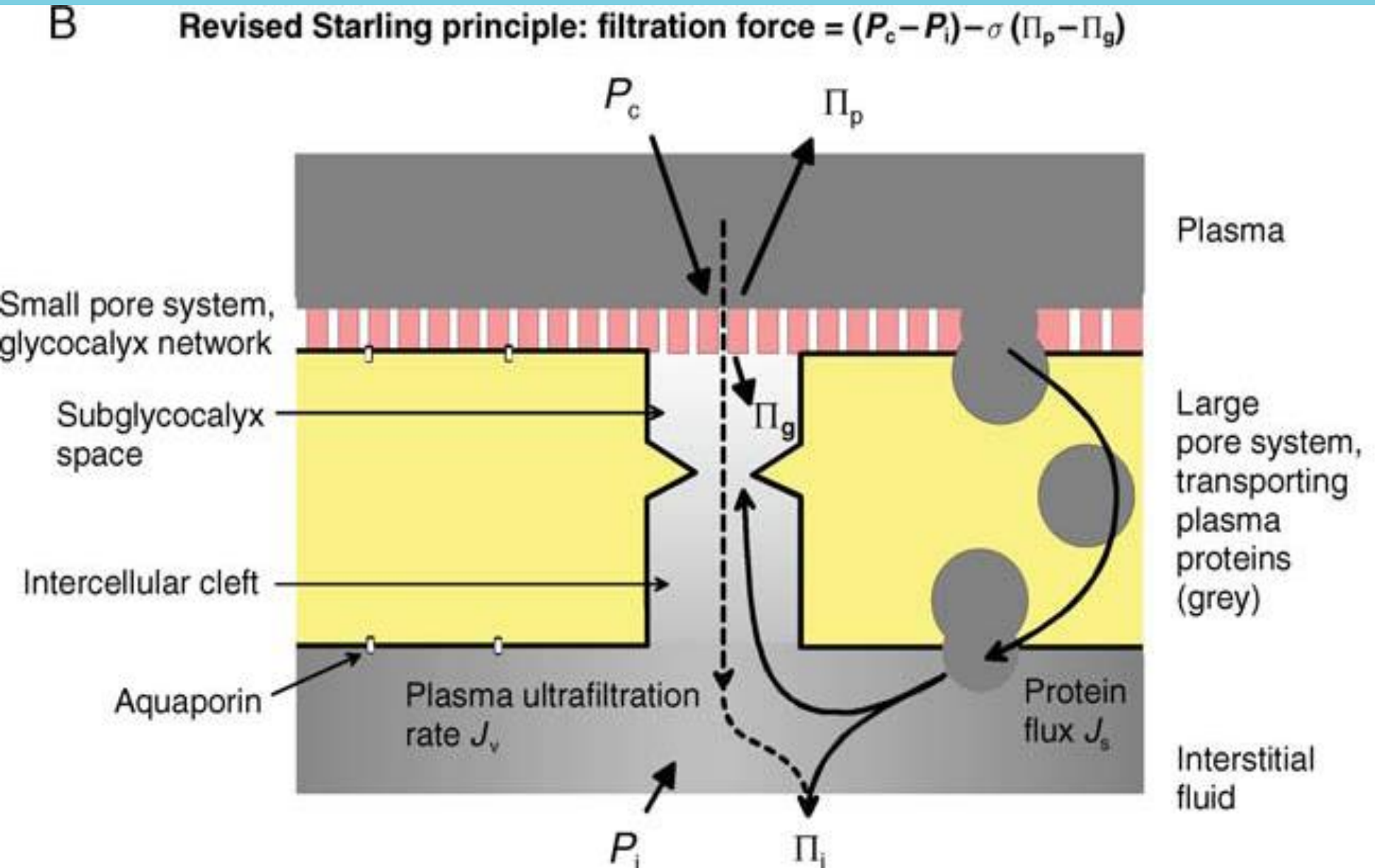
J. Rodney Levick1 and C. Charles Michel 2*

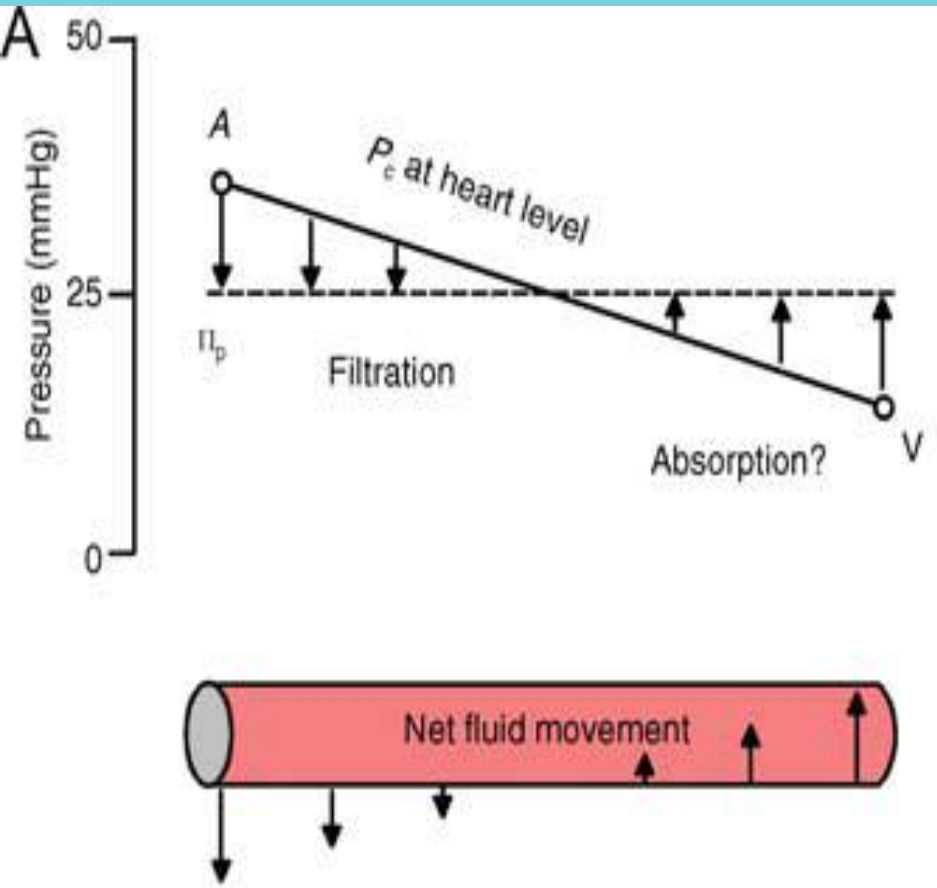
1Physiology, Basic Medical Sciences, St George's Hospital Medical School, London SW17 0RE, UK; and 2Department of Bioengineering, Imperial College, Exhibition Road,
London SW7 2AZ, UK

Received 30 November 2009; revised 4 February 2010; accepted 18 February 2010; online publish-ahead-of-print 3 March 2010

Staverman's osmotic reflection coefficient




B
Revised Starling principle: filtration force = $(P_c - P_i) - \sigma(\Pi_p - \Pi_g)$
P_c
Π_p
Plasma
Small pore system, glycocalyx network
Π_g
Subglycocalyx space
Large pore system, transporting plasma proteins (grey)
Intercellular cleft
Aquaporin
Plasma ultrafiltration rate J_v
Protein flux J_s
Interstitial fluid
P_i
Π_i

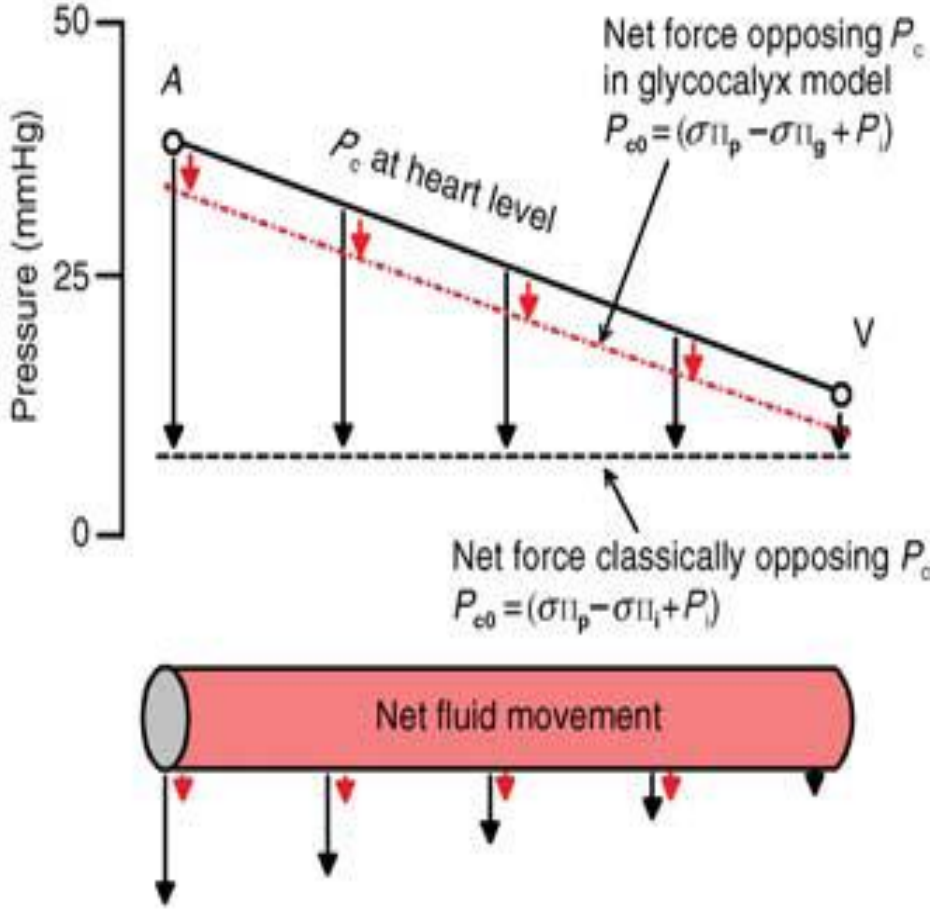


Interstitial forces considered small & negligible

$P_{c0} = \Pi_p = 25$ mmHg

$P_v = 7.7 \pm 1.9$ mmHg (human arm, heart level)

i



Interstitial forces measured in human subcutis

$P_i = -2.1 \pm 2.2$ mmHg. $\Pi_i = 15.7 \pm 2.8$ mmHg

$P_{c0} = 6.3$ mmHg (classic Starling sum)

$P_v = 7.7 \pm 1.9$ mmHg (human arm, heart level)

ii

Starling: yesterday & today

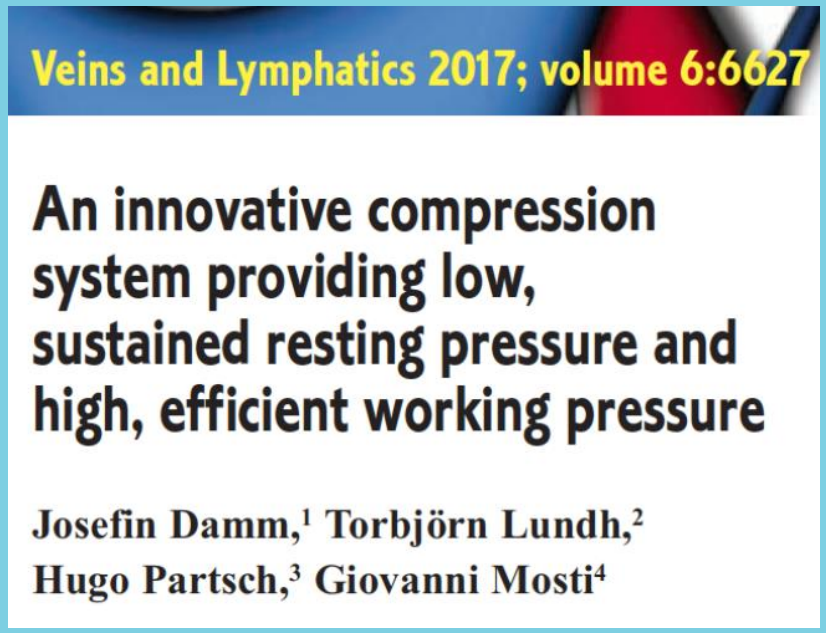
- **1896 Starling: equilibrium between plasma and interstitium**

- **2010 Rodley *(Cardiovasc Research):***

  Tissue colloid osmotic pressure to low to refill the capillaries

Treatment of edema

- Treat the course first
- Compression second



Compression Therapy

Pressure exerted by compression:

- Reduction of the diameter of veins
- Increase in the speed of the venous blood flow
- Improvement of the filtration / reabsorption ratio in the capillaries
- Improved oxygenation of the skin
- Reduction of edema

Compression and edema

Ann Vasc Dis. 2012; 5(4): 416–422.
Published online 2012 Nov 15. doi: 10.3400/avd.ra.12.00068

Compression Therapy: Clinical and Experimental Evidence

Hugo Partsch, MD, PhD

- **Normally expressed as *interface pressure***

  depending on Laplace low

- **This pressure is conducted to deeper structures (subcutaneous tissue / muscles / veins, etc)**

  depending on Pascal low

Three mayor characteristics: 1

Elasticity:

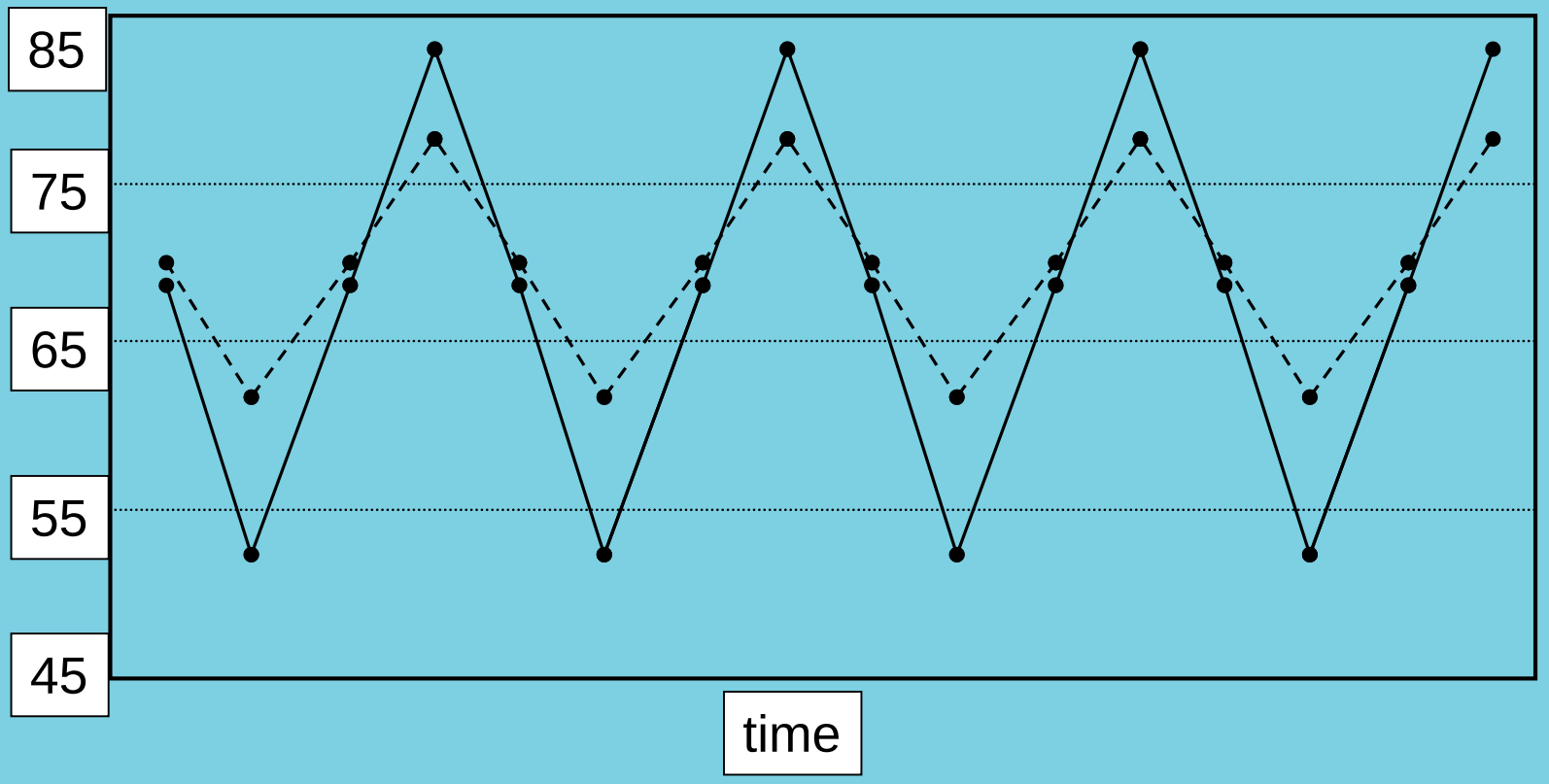
- Naturel or synthetic rubber
- Elasticity is the capacity of material / fabric to return to its original dimension and shape after is has been stretched/elongated.

Elastic / Non-elastic compression

- **Elastic**: ***High*** working and
  high resting pressure

- **Non-elastic**: ***High*** working but
  low resting pressure

Short stretch versus elastic bandage



Maximum and minimum pressures measured underneath a short-stretch (unbroken line) and elastic bandage (dotted line) at the B-area during walking on a treadmill

Compression & Pressure

Working pressure: upright position / walking

+ gravitation

Resting pressure: supine position

- gravitation

Ratio of maximum working and (low) resting pressure

correlates with improvement in venous

refill time ($p<0,001$)

Häfner HM, Eichner M, Jünger M, Medizinische Kompressionstherapie,Zentralbl Chir 126: 551-6, 2001

Three mayor characteristics: 2

Elasticity coefficient / stiffness:

normal tension at B_1 + 1 cm

Increase in pressure due to the elastic material measured in static condition

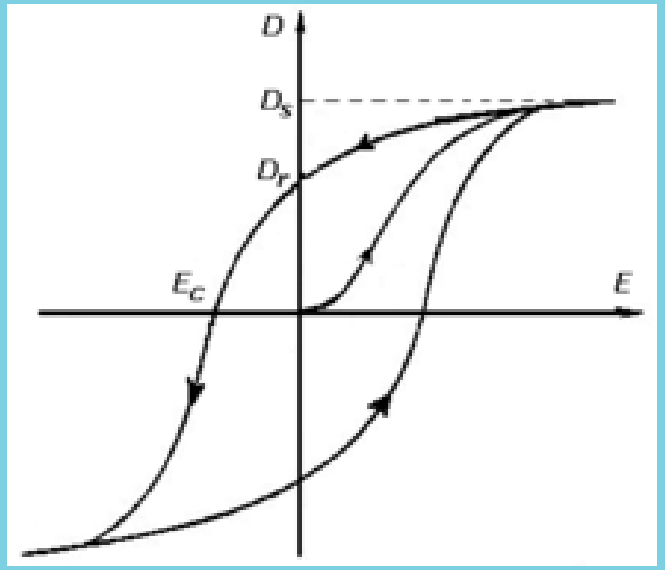
Three mayor characteristics: 3

Hysterisis:

Retardation of the knitted material measured in dynamic condition

Hysteresis

- Greek: lagging / to be detained
- Characteristic of material
- Result of internal friction
- Force-elongation curve



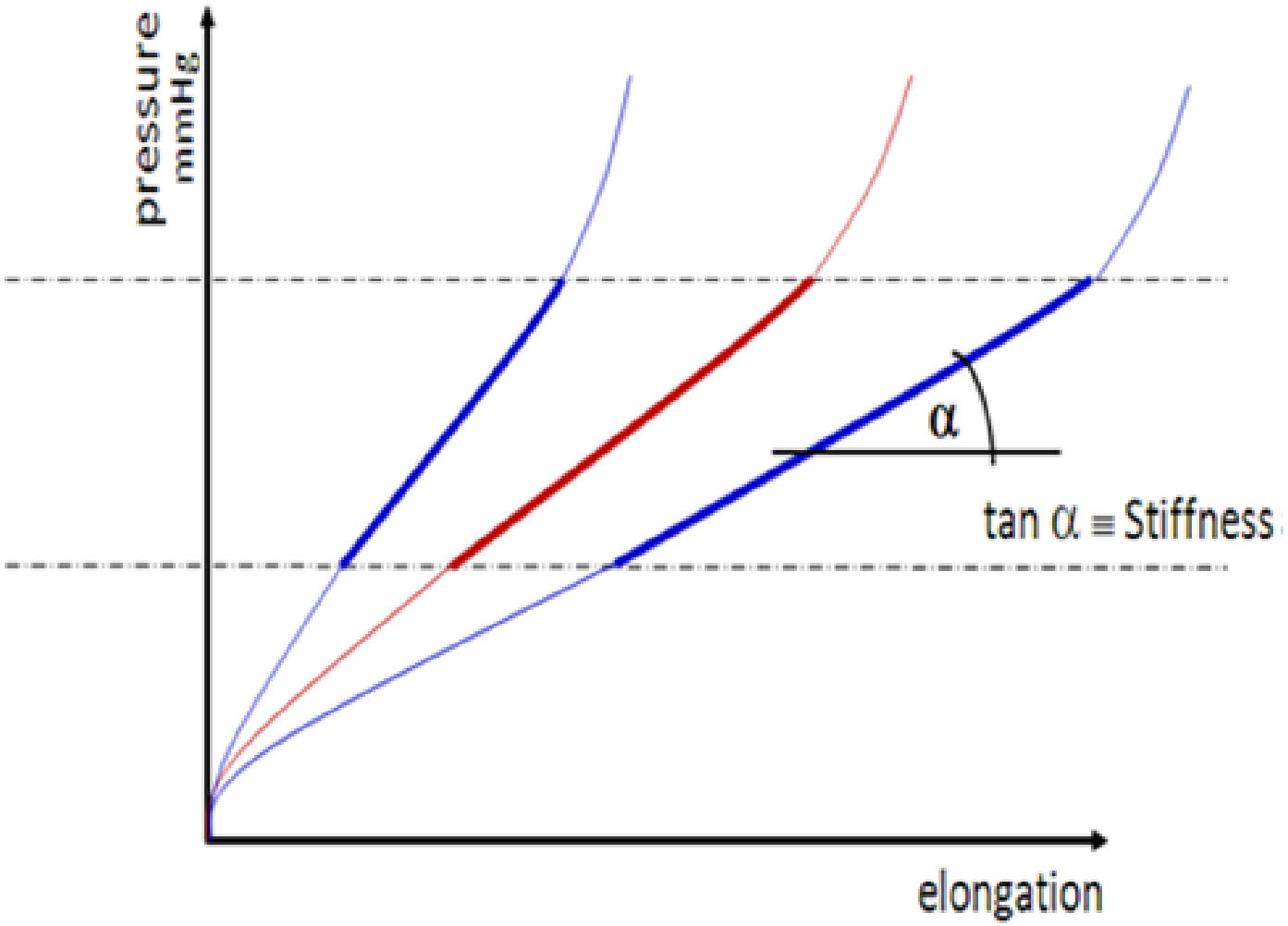


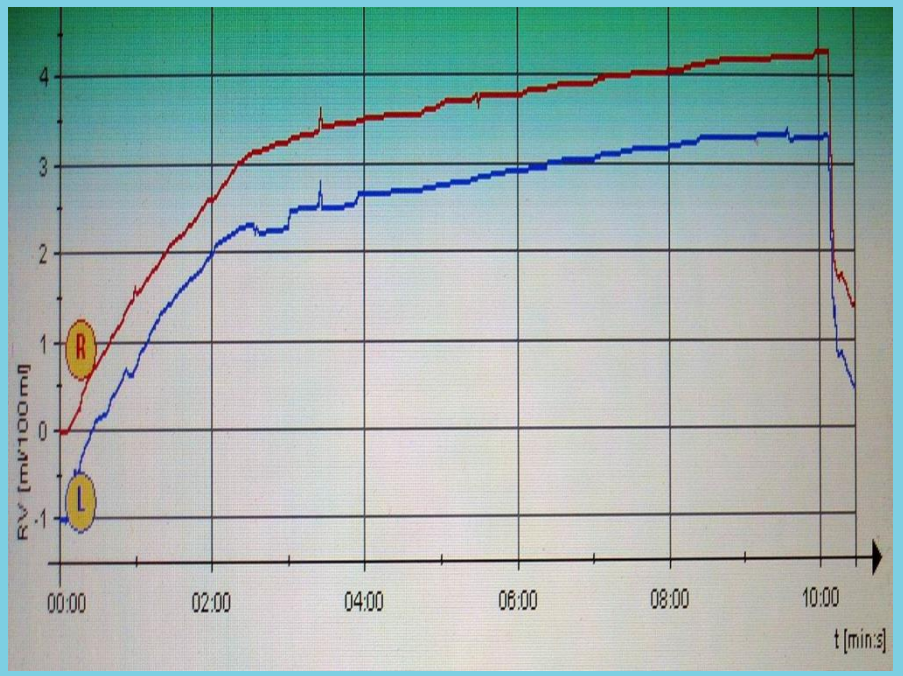
Figure 3: One way hysteresis curves from 3 different stockings. The steepness of the curves (pressure /elongation, corresponding to the tangent of the angle α) characterizes different degrees of stiffness: high (left), medium (middle) and low stiffness (right). (Courtesy of HJ Thomae, Bauerfeind AG)

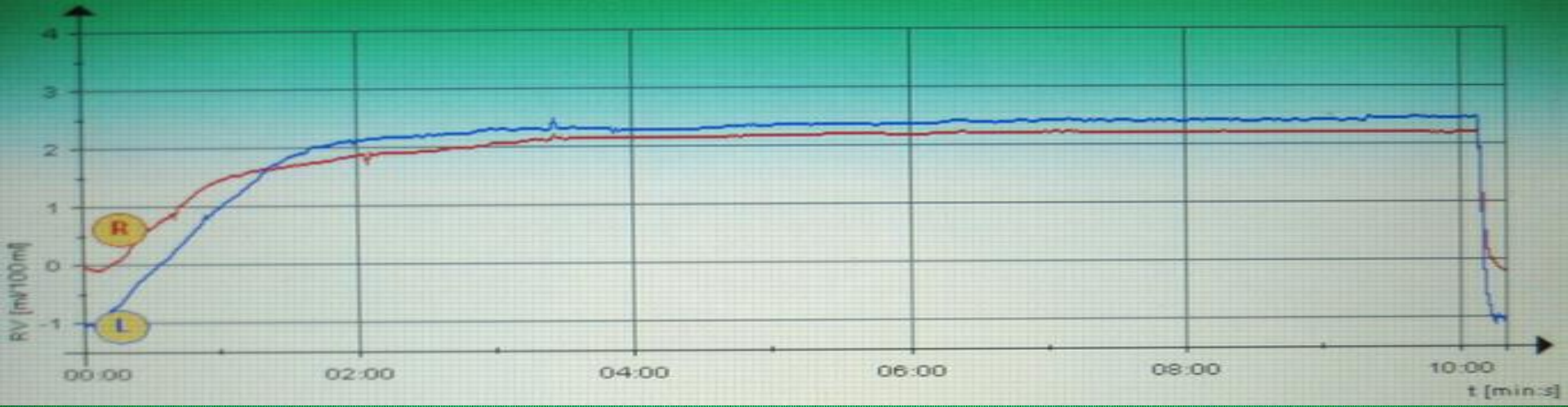
Relation stiffness and CFR

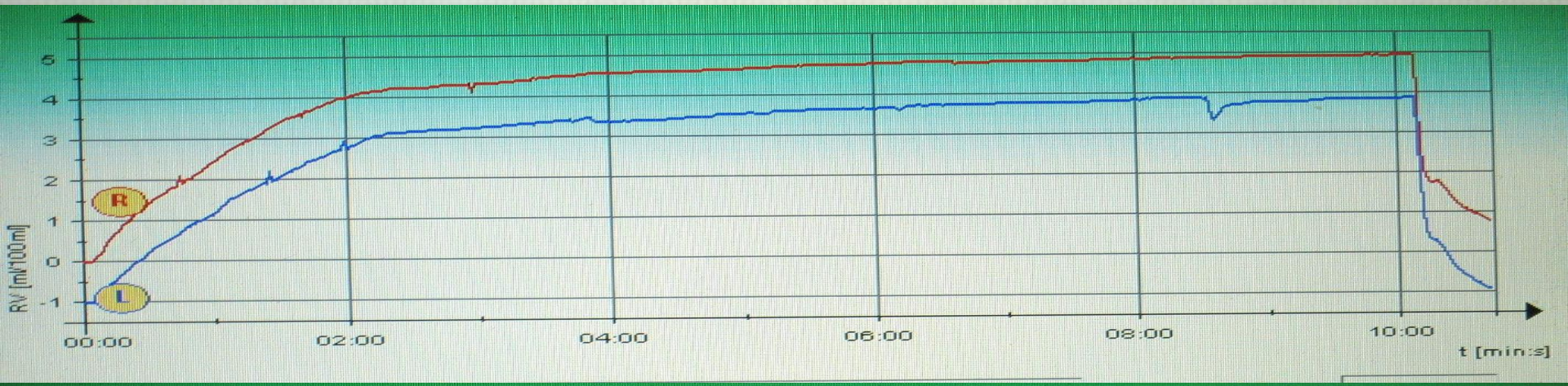
Oedema prevention of MECS depends on stiffness

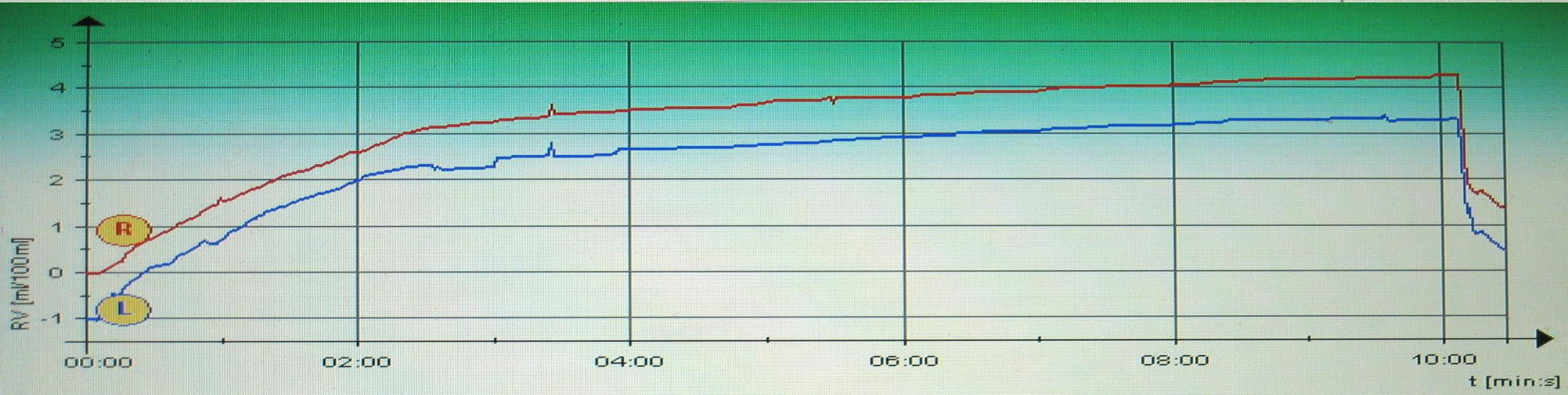
Van Geest A et al., Dermatol. Surg. 26:244-247, 2000

Wolff O, Wentel D, Reeder SWI, Neumann HAM. The effect of compression ulcer stockings on the capillary filtration rate and the formation of edema. Phlebologie 2011; 40:245-250.

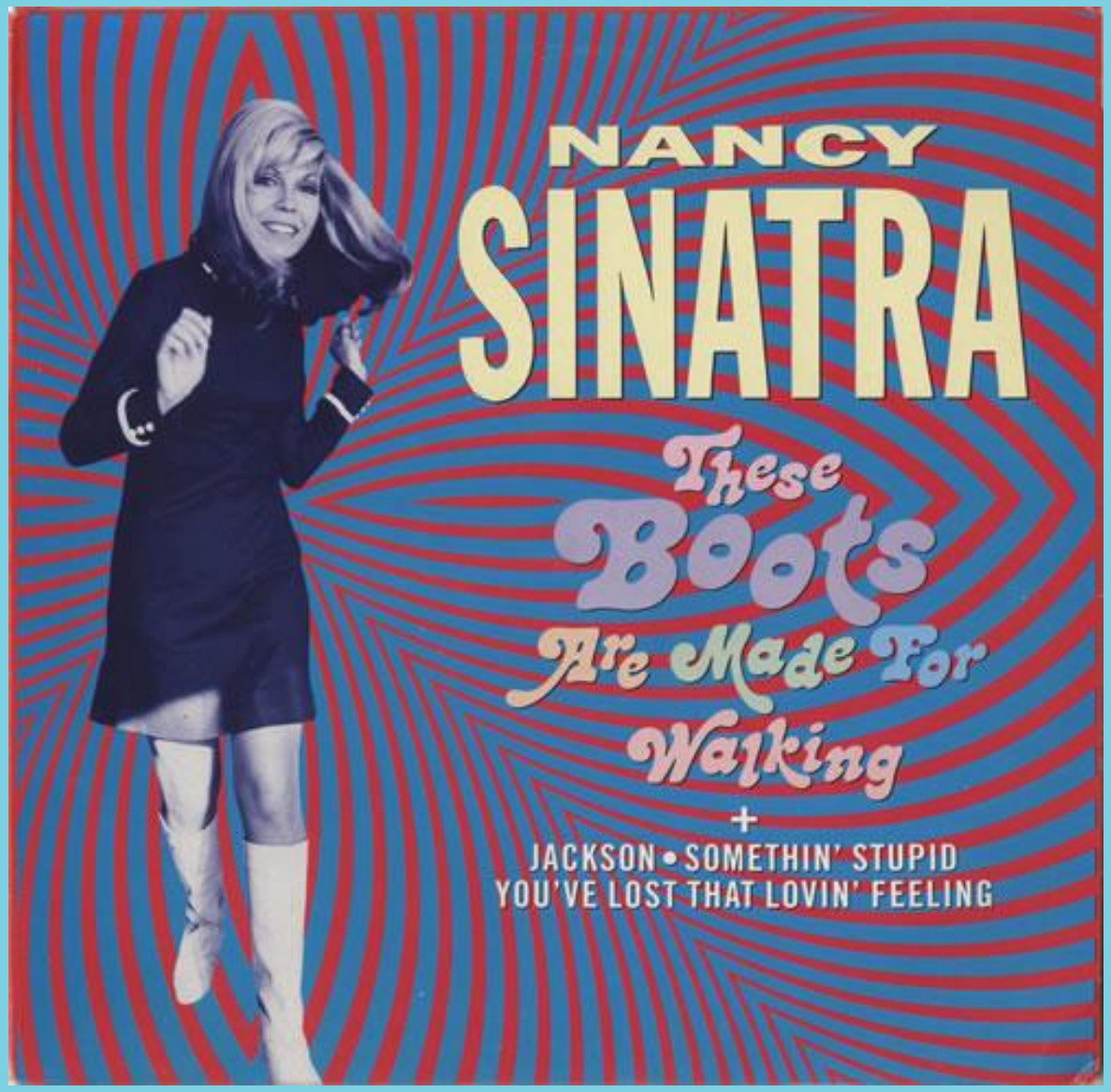



RV [mV/100ml]
4
3
2
1
0
-1
R
L
00:00
02:00
04:00
06:00
08:00
10:00
t [min:s]


RV [mV/100ml]
5
4
3
2
1
0
-1
R
L
00:00
02:00
04:00
06:00
08:00
10:00
t [min:s]


RV [mV/100ml]
5
4
3
2
1
0
-1
R
L
00:00
02:00
04:00
06:00
08:00
10:00
t [min:s]

From static to dynamic



The 4 th Character of CT

Compression most effective during walking

Walking changes static into dynamic

Interface pressure depending on movements

Dynamic elasticity / stiffness coefficient

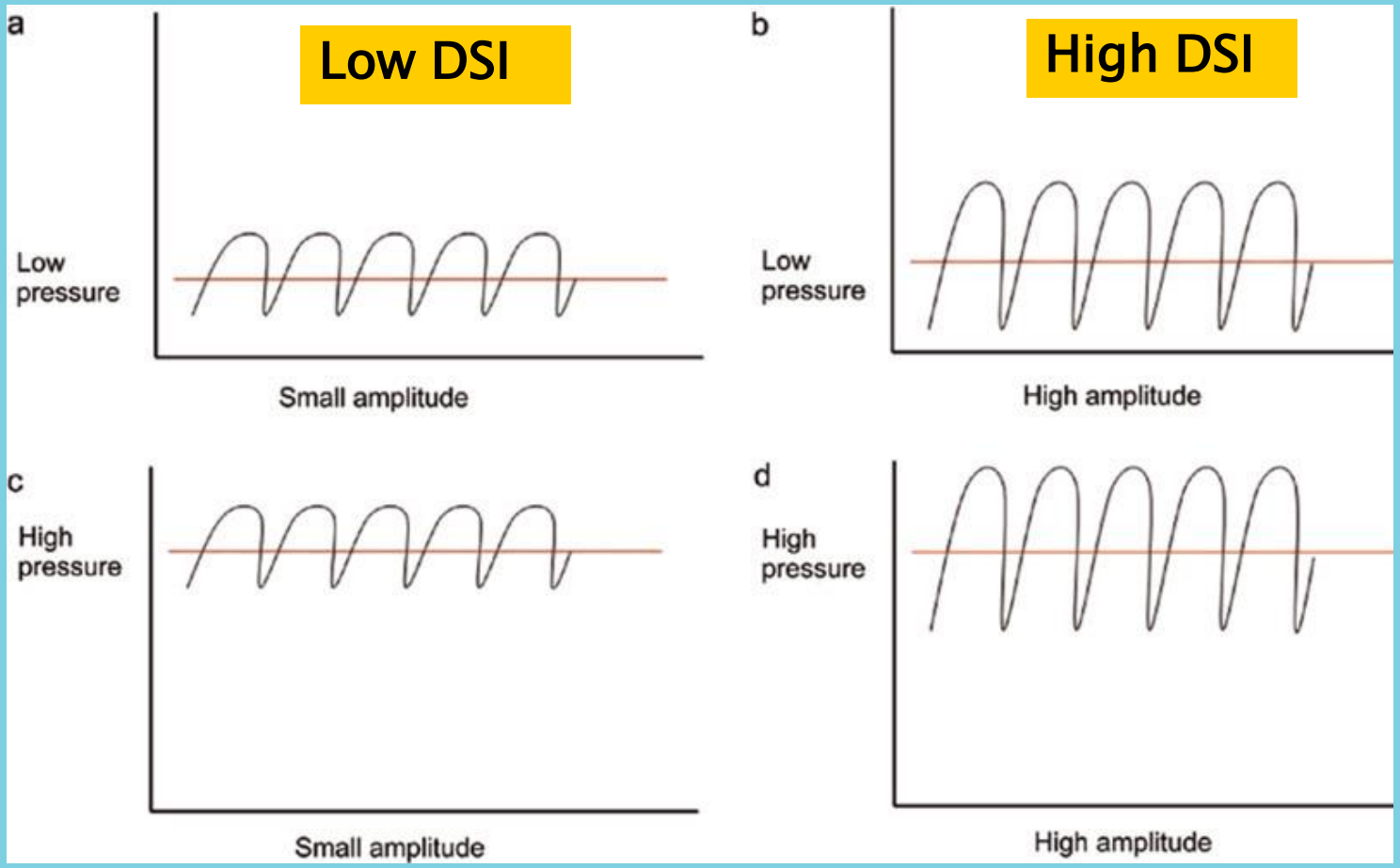
Dynamic stiffness index (DSI)

DSI up to tenfold higher than static stiffness index

	Circumference variation of the MCH in cm	Pressure changes in the air-filled drum in mmHg	Calculated DSI in mm Hg / cm
Exp.#150 MCH	2.82 % x 25.0 cm = 0.70 cm	From 10.8 to 51.2 mm Hg, this is 40.4 mm Hg	40.4 / 0.70 = 58 mm Hg / cm
Exp.#151 MCH with non-elastic material	2.75 % x 25.0 cm = 0.69 cm	From 1.5 to 57.3 mm Hg, this is 55.8 mm Hg	55.8 / 0.69 = 81 mm Hg / cm

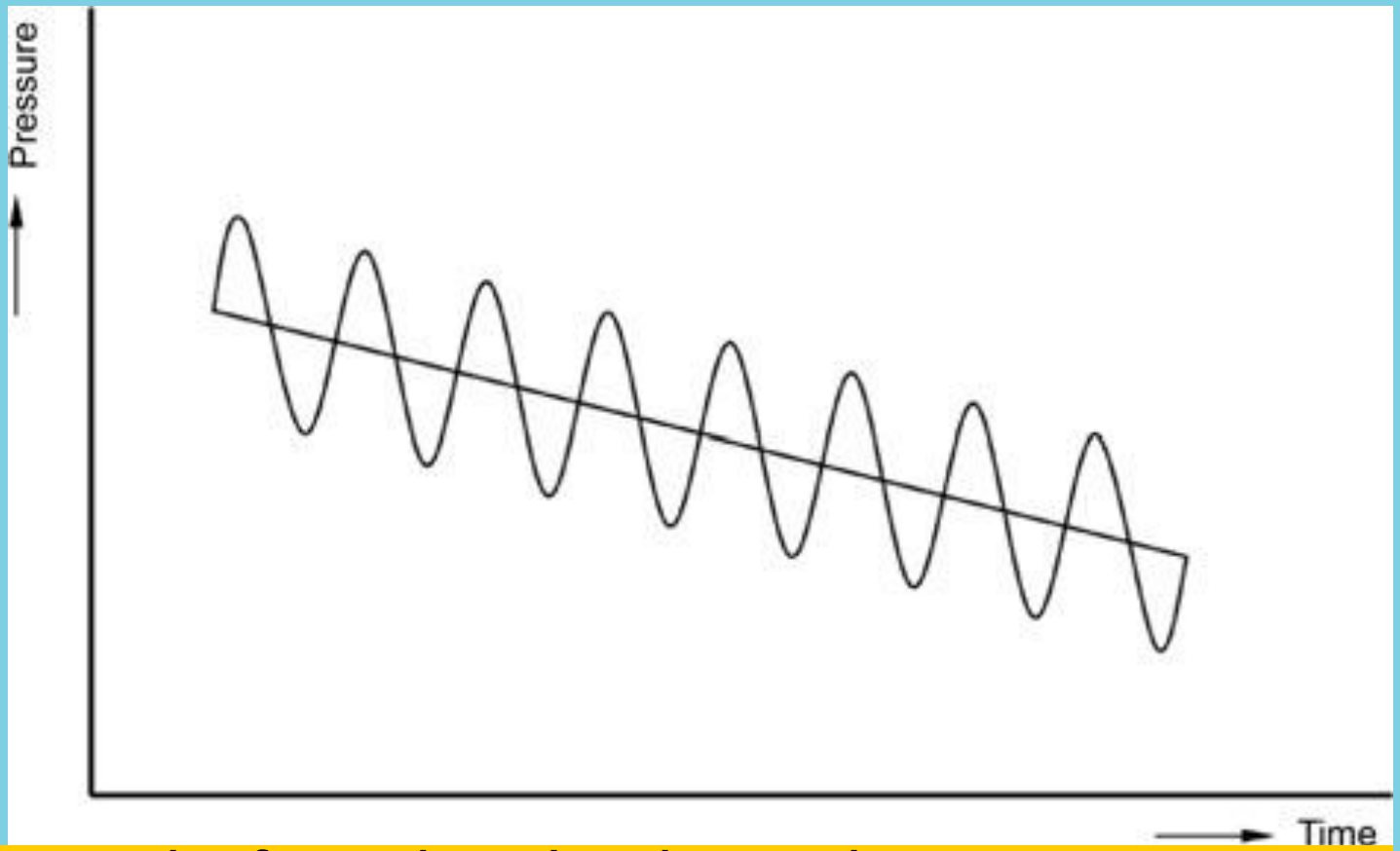
Stolk R et al., Dermatol. Surg 30:729-36, 2004

DSI and pressure



Four types of registration curves: (a) MECS with low compression and low DSI; (b) MECS with low compression and high DSI; (c) MECS with high compression and low DST; (d) MECS with high compression and high DSI (vd Wegen, et al)

DSI and pressure in time



Example of a stocking that shows a decrease in pressure and continuous pressure pulsations (dynamic stiffness index) during the day (vd Wegen, ed. al)

Dynamic Stiffness

- **Correlates with static stiffness**

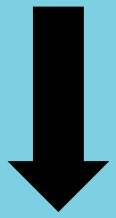
  (vd Wegen)

- **Correlates with density = hysteresis**

  (vd Wegen)

Edema reduction

Alternating interface pressure (**Laplace**)



Increases tissue pressure (**Pascal**)

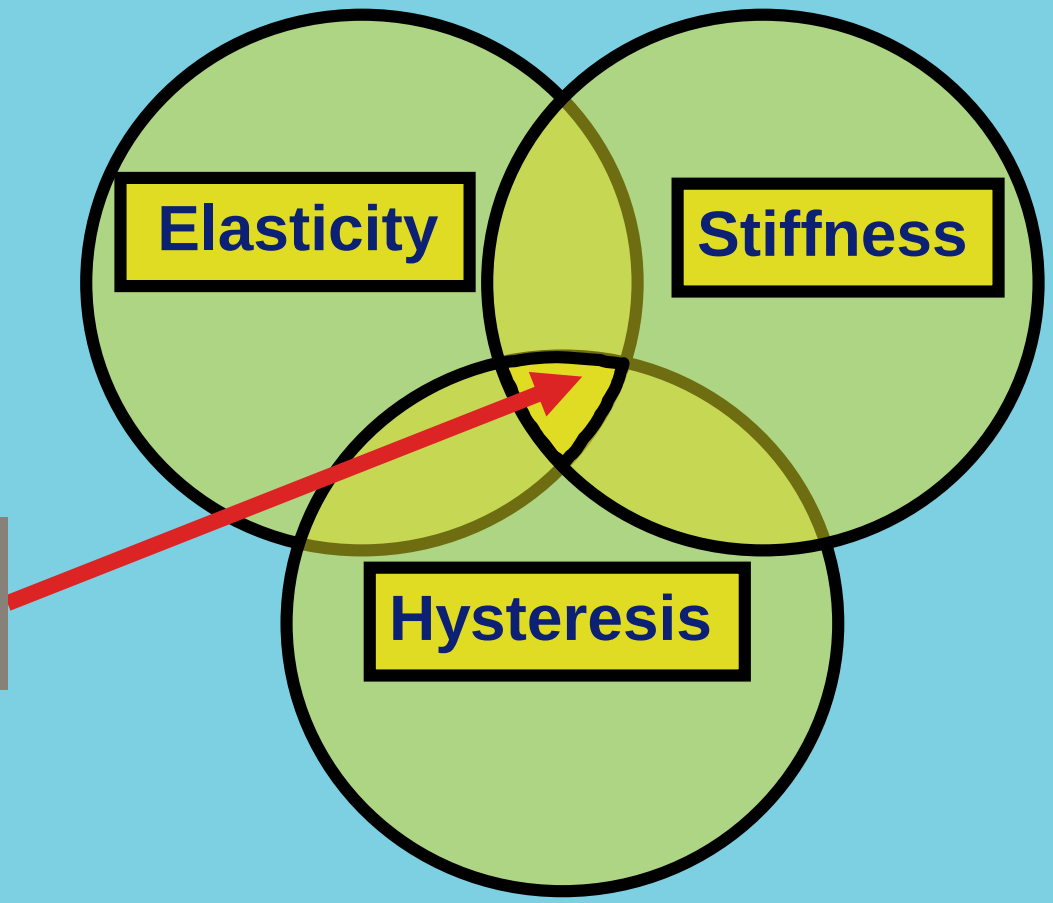
Shifts **Starling** equilibrium: reduce edema by microcirculation

Stiffness or pressure ?

- Effectiveness of ambulatory compression is highly determent by dynamic stiffness
  - Massage effect
  - Starling shift

- Non-ambulatory (dependency) is depending on interface pressure only
  - Counter-pressure only
  - And therefor less effective by the same interface pressure as in ambulatory conditions

The magic triangle



Dynamic compression

As stockings are ….

Conclusions

1. **The DSI defines the quality of compression expressed as interface pressure: Laplace low**
2. **The composition of the tissue defines the final effect *in* the leg: Pascal low**
4. **Stiffness is the major factor for ambulatory reduction of edema**
5. **Interface pressure is the major factor of edema reduction in dependency**