Stiffness & edema

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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

Venous hypertension

- capillary hypertension
  - leakage
  - dilatation
  - flow
  - coagulation
  - venectasia
  - increase reflux
  - varicosity
  - increase venous volume
  - decreased pump capacity
  - inflow
  - function

- increased reflux
- increased venous volume

- proteins
- water
- erythrocytes
- edema
- white atrophy
- pigmentation
- Dermato-et lipo-et fasciosclerosis
- decreased joint movements
- decreased pump capacity

- ulcer
SPOTLIGHT REVIEW
Microvascular fluid exchange and the revised Starling principle
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Staverman’s osmotic reflection coefficient

A Classic Starling principle: filtration force = \( (P_c - P_i) - \sigma (\Pi_p - \Pi_i) \)
Revised Starling principle: filtration force = \((P_c - P_i) - \sigma (\Pi_p - \Pi_g)\)
A

Interstitial forces considered small & negligible

\[ P_{co} = \Pi_p = 25 \text{mmHg} \]
\[ P_v = 7.7 \pm 1.9 \text{mmHg} \text{ (human arm, heart level)} \]

B

Net force opposing \( P_c \) in glycocalyx model
\[ P_{co} = (\sigma_{II_p} - \sigma_{II_I} + P_i + P_l) \]

Net force classically opposing \( P_c \)
\[ P_{co} = (\sigma_{II_p} - \sigma_{II_I} + P_i) \]

Interstitial forces measured in human subcutis
\[ P_i = -2.1 \pm 2.2 \text{mmHg} \]
\[ \Pi_l = 15.7 \pm 2.8 \text{mmHg} \]
\[ P_{co} = 6.3 \text{mmHg} \text{ (classic Starling sum)} \]
\[ P_v = 7.7 \pm 1.9 \text{mmHg} \text{ (human arm, heart level)} \]
Starling: yesterday & today

- 1896 Starling: equilibrium between plasma and interstitium

- 2010 Rodley *(Cardiovasc Research)*:
  
  Tissue colloid osmotic pressure too 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

- Normally expressed as interface pressure depending on Laplace law
- This pressure is conducted to deeper structures (subcutaneous tissue / muscles / veins, etc) depending on Pascal law
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
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)

Three mayor characteristics: 2

Elasticity coefficient / stiffness:

normal tension at $B_1 + 1 \text{ cm}$

Increase in pressure due to the elastic material measured in static condition
Hysterisis:
Retardation of the knitted material measured in dynamic condition

Three mayor characteristics: 3
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 $\alpha$) 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


From static to dynamic

NANCY SINATRA

These Boots Are Made For Walking

JACKSON • SOMETHIN' STUPID
YOU'VE LOST THAT LOVIN' FEELING
The 4\textsuperscript{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

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

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 therefore less effective by the same interface pressure as in ambulatory conditions
The magic triangle

- Elasticity
- Stiffness
- Hysteresis

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