Endothelium

- A type of epithelium that lines the interior surface of blood vessels and lymphatic vessels
- Single layer of squamous endothelial cells with tight junctions
Figure 1. Endothelium and permeability.

A  Capillary

Continuous Non-fenestrated
- Lumen
  - Caveolae
  - TEC (transendothelial) channel
  - Intercellular cleft
- H₂O small solutes
- Tracer

Skin
- Lung
- Heart

Continuous fenestrated
- Lumen
  - Diaphragm
- H₂O small solutes
- Tracer

Endocrine glands
- GI mucosa
- Glomerulus

Discontinuous/sinusoidal
- Lumen
  - Sinusoidal fenestrae / Gaps
- H₂O small solutes
- Tracer

Liver

B  Post-capillary venule

Lumen
- VVO

Intercellular cleft
- Caveolus opening into cleft

Inflammation

I
- Fluids and solutes
- Widening of intercellular cleft

II
- Fluids and solutes

William C. Aird Circ Res. 2007;100:158-173

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Endothelial cell

• Large amounts of vesicles and caveolae along the luminal surface - transendothelial transport of biologically active substances
Endothelium

- **Mesodermal** origin
- EC are aligned and elongated in direction of flow
- EC line the **entire circulatory system** – one of the largest organ systems
- Unique functions
Endothelium

• Fluid filtration (glomeruli)
• Barrier function
• Blood vessel tone (vasodilation and vasoconstriction)

• **Hemostasis**
• Hormone trafficking
• Inflammation - neutrophil recruitment
• Angiogenesis
• Secretion of mediators – normal vascular function
Barrier function

Endothelial cell

Apical plasma membrane

Adherens junction

VE-cadherin

Catenin

Vinculin

Actin (cytoskeleton)

JAM

Occludin

Claudin

TJP1

TJP2

TJP3

Actin (cytoskeleton)

Spectrin

FIGURE 4 | Scheme of a protein structure of endothelial intercellular junctions (EIJs).
Figure 2. Endothelium and leukocyte trafficking.

William C. Aird Circ Res. 2007;100:158-173
FIGURE 3 | Penetration of a blood cell through the endothelium into the arterial intima. Scanning electron microscopy (SEM). Scale bar = 5 μm. Image is adapted from Bobrovshev (1983).
Figure 4. Mechanisms of EC heterogeneity.

A

Differentiation

-/-

/-/

++

++++++

Hemangioblast

Hematopoietic stem cell

Artery

Vein

Capillary

Brain

Heart

Kidney

Time

Microenvironment

(Not transmitted during mitosis)

-/-

/-/

++

++++++

Epigenetics

(Transmitted during mitosis)

++++++

++++

++

+

B

Microenvironment

Protein

Post-translational modification

Transcription factor

Nucleus

C

Epigenetics

Histone

CH3

H3

H4

Methylation balance

Methylase

Demethylase

HAT

HDAC

Acetylation balance

William C. Aird Circ Res. 2007;100:158-173
FIGURE 2 | Endothelial function in the norm. Arterial endothelial cells are involved in the maintenance of vascular homeostasis by providing balanced release of vasodilatating/vasoconstricting factors and prothrombotic/antithrombotic substances that inhibits the endothelial adhesion of leukocytes and thus, prevents the initiation of vascular inflammation.
Endothelial dysfunction

- Systemic pathological state of the endothelium
- **Imbalance** between vasodilating and vasoconstricting substances produced by the endothelium
- Shift of the balance in favour of **vasoconstrictive**, **pro-inflammatory** and **pro-thrombotic** effects
- Mainly due to reduced bioavailability and bioactivity of **nitric oxide (NO)**
Vasodilation

- Nitric oxide
- EDHF
- Prostacyclin
- Acetylcholine
- Bradykinin
Nitric oxide

- Most abundant free radical in the body
- Halflife of NO is affected by its chemical reaction and inactivation by superoxide anion
- \( \cdot O_2^- + \cdot NO \rightarrow ONOO^- \)
Shear stress

• A stress state where the stress force is parallel to the surface of the vessel (ass opposed to normal stress, where the stress is vertical)

• Force exerted on vessel wall / cross-sectional area

• NO is released after shear stress in the vessel – vasodilation

• NO mediated vasodilation decreases shear stress

• If shear stress is chronic – upregulation of inflammatory cytokines – endothelial dysfunction
Protective effects of NO

- Smooth muscle relaxation and vasodilation
- Lowering blood pressure
- Reducing proliferation of vascular smooth muscle
- Inhibition of platelet aggregation
- Inhibition of expression of VCAM and ICAM
Vasoconstriction

• Endothelin-1
• Prostaglandin $\text{H}_2$
• Thromboxane $\text{A}_2$
• ROS
• Endothelium-bound ACE – angiotensin II
Regulatory Functions of the Endothelium

**Normal**
- Vasodilation: NO, PGI2, EDHF, BK, C-NP
- Thrombolysis: tPA, Protein C, TF-I, vWF
- Platelet Disaggregation: NO, PGI2
- Antiproliferation: NO, PGI2, TGF-β, Hep
- Lipolysis: LPL

**Dysfunction**
- Vasoconstriction: ROS, ET-1, TxA2, A-II, PGH2
- Thrombosis: PAI-1, TF-α, Tx-A2
- Adhesion Molecules: CAMs, P, E Selectins
- Growth Factors: ET-1, A-II, PDGF, ILGF, ILs
- Inflammation: ROS, NF-κB

Vogel R
The endothelium maintains vascular health

Dilatation
Growth inhibition
Antithrombotic
Anti-inflammatory
Antioxidant

Constriction
Growth promotion
Prothrombotic
Proinflammatory
Pro-oxidant
What causes Endothelial Dysfunction?

Negatively Affect
- Smoking
- Diabetes
- High Blood Pressure
- High Cholesterol
- Weight Gain
- Mental Stress
- Excessive Inflammation

Positively Affect
- Exercise
- Weight Loss
- Stress Reduction
- Cholesterol-Lowering Drugs
Consequences of ED

- EC as progenitor of atherosclerosis (ED is present long before onset of symptoms)
- EC as predictor of future cardiovascular events

*Fig. 1 From the causes to the consequences of endothelial dysfunction. CAD coronary artery disease, OSA obstructive sleep apnea, PAD peripheral artery disease*
Oxidative stress

• **Imbalance** between production of reactive oxygen species and ability of the system to detoxify the reactive intermediates or to repair the damage

• Key mechanism of endothelial dysfunction

• OS + ED are major factors for atherosclerosis
Oxidative stress leads to endothelial dysfunction and reduced NO bioavailability, which in turn causes:

- Leukocyte adhesion and inflammation
- Platelet aggregation and thrombosis
- Lipid deposition
- Vascular smooth muscle cell proliferation
- Vasoconstriction

These processes contribute to the progression of atherosclerosis and cardiovascular disease.
LDL-specific antioxidant action

Native LDL

Vessel lumen

Endothelial cells

Vessel wall

Antioxidants impair cellular capacity to oxidize LDL

Oxidants

Vascular cells

Oxidants

Antioxidants limit cellular responses to oxidized LDL

Oxidized LDL

Antioxidants inhibit LDL oxidation by oxidants

Cellular responses to oxidized LDL

† Monocyte adhesion  † Foam-cell formation  † Cytotoxicity  † Vascular dysfunction

Formation and activation of atherosclerotic lesions
SOD = Superoxide Dismutase
CAT = Catalase
GPx = Glutathione Peroxidase
GR = Glutathione Reductase
L-Arg = L-Arginine
L-Cit = L-Citrulline
ONOO− = Peroxynitrite
•ON = Nitric Oxide
O2− = Superoxide
H2O2 = Hydrogen Peroxide
H2O + O2
L-Cit = L-Citrulline
GSH
NADPH
GSSG
+2GSH
NADP+
H2O2 + [O]
H2O + O2
SOD
Heme-Fe2+−NO
•NO
ONOO−
Heme-Fe2+−SH
NADP+
NADPH
L-Arg
L-Cit
GSH
Gr
H2O
GSSG
GPx
ED in disease

- Cardiovascular disease
- Diabetes
- Transplant vasculopathy
- Autoimmune diseases
- Celiac disease and irritable bowel syndrome
- Hematologic disorders
- Neurocognitive disorders
- Cirrhosis
1. ED in diabetes

- T1DM, T2DM
- Pathogenesis unclear
- Multifactorial etiology of ED
- 1. Insulin resistance
- 2. Pro-inflammatory signalling
- 3. Oxidative stress
- 4. Protein kinase C
- 5. Hyperglycemia
Insulin resistance in ED

• Insulin activates vasoprotective pathways
  • PI3K/Akt – eNOS expression and activation
• In contrast, MAPK/ERK pathway promotes ET-1 and cellular proliferation
• In physiological conditions – PI3K predominates
• Insulin resistance – PI3K deficiency, MAPK predominates – proatherogenic signalling
**MAP kinase pathway**
- Growth signalling
- Proliferation
- Differentiation
- Inflammation
- Gene expression

**PI3-kinase pathway**
- Glucose uptake
- Glycogen/protein/lipid synthesis
- eNOS phosphorylation

Roberts and Porter 2013
Pro-inflammatory signalling in ED

• Adipose tissue produces inflammatory cytokines
• **TNFalpha, free fatty acids, RAGE** activate **NFKB** that further stimulates expression of inflammatory genes in endothelium
• Reduction of NO expression
Oxidative stress in ED

- OS as a unifying mechanism of endothelial injury
- OS leads to **diminished NO bioavailability**
  - Direct degradation of NO
  - Alterations in functional capacity of eNOS
Protein kinase C in ED

- PKCbeta is endothelial isoform of serin/threonine kinase
- Main contributor to ED observed in diabetes
- High FFA and glucose – high DAG (de novo from glucose) – activation of PKCbeta – induction of downstream events:
  - ET-1
  - VCAM
  - ICAM
  - NADPH oxidase
  - NFkB
  - Inhibition of PI3K and eNOS
Hyperglycemia in ED

• 1. PKC activation
• 2. Activation of hexosamine pathway – PKC
• 3. Activation of polyol pathway – PKC
• 4. Formation of advanced glycation end-products

• Unifying mechanisms is ROS overproduction
2. ED in hypertension

- ED as an *early event* in pathophysiology of *essential hypertension* that contributes to subclinical target organ damage and progression of atherosclerosis
  - Defective endothelial L-arginine/NO pathway
  - Impaired responsiveness to exogenous NO
  - Reduced generation of platelet NO
  - In the presence of oxidatove stress
- Pro-inflammatory, pro-atherosclerotic, pro-thrombotic phenotype
Mechanism of ED in hypertension

- Hypertension as **cause** rather than consequence of endothelial dysfunction
- Hypertension-induced oxidative stress
Measuring endothelial function

• 1950s – endothelium as a dynamic organ with diverse capabilities
• Invasive methods
• 1992 – Celermajer et al. proposed first non-invasive method for assessment of endothelial function - diameter of superficial femoral and brachial arteries
  • At rest
  • During reactive hyperemia (endothelium-dependent dilatation)
  • After sublingual nitroglycerin (endothelium-independent dilatation)
<table>
<thead>
<tr>
<th>Criteria for an Optimal Endothelial Function Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reflects disease state</td>
</tr>
<tr>
<td>Reversible with interventions</td>
</tr>
<tr>
<td>Mirrors coronary endothelial function</td>
</tr>
<tr>
<td>Improves risk stratification</td>
</tr>
<tr>
<td>Reproducible</td>
</tr>
<tr>
<td>Operator independent</td>
</tr>
<tr>
<td>Noninvasive (no or low risk for the patient)</td>
</tr>
<tr>
<td>Ease of use</td>
</tr>
<tr>
<td>Inexpensive</td>
</tr>
</tbody>
</table>
Vascular markers of ED

- Quantitative coronary angiography
- MRI
- PET
- Invasive measurement of forearm blood flow (FBF) by venous occlusion plethysmography
Vascular markers of ED

- Non-invasive measurement
  - Flow-mediated dilation (FMD) – macrovascular function
  - Peripheral arterial tonometry – microvascular function
  - Laser Doppler flowmetry

Figure 3A. Diagram of PAT device on digit.
<table>
<thead>
<tr>
<th>Technique</th>
<th>Vascular Bed</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Stimulus (Examples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronary epicardial vasoreactivity (QCA)</td>
<td>Epicardial macrovascular Conduit arteries</td>
<td>Assessment directly in the coronary vascular bed</td>
<td>Invasive</td>
<td>Ach</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cold standard</td>
<td>Expensive</td>
<td>Exercise</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Time intensive</td>
<td>Pacing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Limited to those undergoing coronary angiography</td>
<td>CPT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Challenging for serial measurements</td>
<td></td>
</tr>
<tr>
<td>Coronary microvascular function–Doppler wires</td>
<td>Coronary microvascular Resistance arteries</td>
<td>Assessment directly in the coronary microvasculature</td>
<td>Invasive</td>
<td>Ach</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Expensive</td>
<td>Adenosine</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Time intensive</td>
<td>Papaverine</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Limited to those undergoing coronary angiography</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Challenging for serial measurements</td>
<td></td>
</tr>
<tr>
<td>FMD</td>
<td>Brachial artery</td>
<td>Easy access</td>
<td>Challenging to perform well</td>
<td>Reactive Hyperemia</td>
</tr>
<tr>
<td></td>
<td>Conduit artery</td>
<td>Correlation with invasive epicardial vascular function</td>
<td>Disparate protocols for performance and standardizations</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Many outcome studies</td>
<td>Need for standardization</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Inexpensive</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Possibility to assess other important parameters (flow, baseline arterial diameters, FMC)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Venous occlusion plethysmography</td>
<td>Forearm vasculature</td>
<td>Easy access</td>
<td>Invasive (cannulation of the brachial artery)</td>
<td>Ach and other vasoactive substances</td>
</tr>
<tr>
<td></td>
<td>Microvasculature</td>
<td>Vasoactive substances infused to generate a dose-response relationship</td>
<td>Time consuming</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contralateral arm as a control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EndoPAT</td>
<td>Finger</td>
<td>Easy to access and perform</td>
<td>Expense of disposable finger probes</td>
<td>Reactive hyperemia</td>
</tr>
<tr>
<td></td>
<td>Microvasculature</td>
<td>Automated</td>
<td>PAT signal influenced by variable non endothelial factors</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low interobserver and intraobserver variability</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Correlation with invasive microvascular vascular function</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

QCA indicates quantitative coronary angiography; Ach, acetylcholine; CPT, cold pressor test; FMD, flow-mediated dilation; FMC, flow-mediated constriction; and PAT, peripheral arterial tonometry.
### Table 3. Technical Considerations in Flow-Mediated Dilation Measurements

<table>
<thead>
<tr>
<th>Subject preparation</th>
<th>Site selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fasting state (&gt;6 h)</td>
<td></td>
</tr>
<tr>
<td>No smoking or any tobacco consumption at least 6 h before study</td>
<td></td>
</tr>
<tr>
<td>No exercise or food/beverages that contain alcohol or caffeine or are rich in polyphenols (cocoa, tea, fruit juices) for &gt;12 h</td>
<td></td>
</tr>
<tr>
<td>No vitamins for at least 72 h</td>
<td></td>
</tr>
<tr>
<td>Vasoactive medications withheld on the morning of the study if possible with careful noting of the use and timing of any drugs</td>
<td></td>
</tr>
<tr>
<td>No exercise &gt;12 h before test</td>
<td></td>
</tr>
<tr>
<td>Quiet, temperature-controlled room</td>
<td></td>
</tr>
<tr>
<td>In female patients, repetitive studies should be made at the same time of the menstrual cycle (ideally on days 1–7 of the menstrual cycle)</td>
<td></td>
</tr>
<tr>
<td>Rest for at least 10 min before measurements</td>
<td></td>
</tr>
<tr>
<td>Supine position</td>
<td></td>
</tr>
<tr>
<td>Arm resting comfortable with cradle support with the imaged artery at the heart level</td>
<td></td>
</tr>
<tr>
<td>Test should be performed at the same time of the day (especially if multiple tests are performed)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sphygmomanometer probe position and cuff occlusion time</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Placement of the cuff 1–2 cm distal to the elbow crease</td>
<td></td>
</tr>
<tr>
<td>Other sites are discouraged because proximal cuff positioning affects the magnitude of the peak vasodilatory response</td>
<td></td>
</tr>
<tr>
<td>Occlusion time, 5 min (shorter inflation attenuates FMD response)</td>
<td></td>
</tr>
<tr>
<td>Cuff inflation to at least 50 mm Hg above systolic pressure</td>
<td></td>
</tr>
<tr>
<td>Automated edge detection should be used</td>
<td></td>
</tr>
<tr>
<td>Reported as maximal percentage change from baseline diameter (most reproducible)</td>
<td></td>
</tr>
<tr>
<td>Baseline diameter and absolute change reported also</td>
<td></td>
</tr>
<tr>
<td>Characterization of the hyperemic stimulus (ideally the flow-velocity time integral)</td>
<td></td>
</tr>
</tbody>
</table>

Image acquisition

- Longitudinal images obtained by high-resolution ultrasound (7.5–12 MHz)
- A clear interface between the near and far arterial wall should be achieved
- Diameter measurements are obtained in end diastole or averaged over the heart cycle
- Stereotactic adjustable prop holding is essential to ensure image quality
- Recording of the baseline diameter for at least 1 min
- Simultaneous acquisition of pulse-wave Doppler velocity signals for quantification of shear stress (stimulus) if feasible; insonation angle should be <60°
Biomarkers of ED

• **Assymetric dimethylarginine ADMA** – endogenous competitive inhibitor of NO synthase
• Oxidized LDL
• Endothelial microparticles
• Endothelial progenitor cells
<table>
<thead>
<tr>
<th>Coronary circulation</th>
<th>Peripheral circulation</th>
<th>Circulating biomarkers</th>
</tr>
</thead>
<tbody>
<tr>
<td>QCA</td>
<td>Ultrasonography: FMD</td>
<td>ADMA, NO</td>
</tr>
<tr>
<td>PET</td>
<td>Plethysmography: FABF</td>
<td>ET-1</td>
</tr>
<tr>
<td>MRI</td>
<td>Endo-PAT</td>
<td>hs-CRP</td>
</tr>
<tr>
<td>Echocardiography</td>
<td></td>
<td>vWF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PAI-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ICAM, VCAM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Selectins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EP cells</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EMPs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SNP s</td>
</tr>
</tbody>
</table>

**Vasodilatory stimuli**

- Acetylcholine
- Shear stress
- Nitrates
- NOS inhibitors

**Legend:** QCA - quantitative coronary angiography, PET - positron emission tomography, MRI - magnetic resonance imaging, FMD - flow-mediated dilation, FABF - forearm blood flow, Endo-PAT - non-invasive peripheral artery tonometry, NOS - nitric oxide synthase, ADMA - asymmetric dimethylarginine, NO - nitric oxide, ET-1 - endothelin-1, hs-CRP - high-sensitivity C-reactive protein, vWF - von Willebrand factor, PAI-1 - plasminogen activator inhibitor 1, ICAM - intercellular adhesion molecule, VCAM - vascular cell adhesion molecule, EP cells - endothelial progenitor cell, EMP - endothelial-derived microparticle, SNP - single nucleotide polymorphisms.
ED in periodontitis

Treatment of Periodontitis and Endothelial Function

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Control-Treatment Group (N=59)</th>
<th>Intensive-Treatment Group (N=61)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age — yr</strong></td>
<td>47.8±6.3</td>
<td>47.7±7.9</td>
</tr>
<tr>
<td><strong>Male sex — no. (%)</strong></td>
<td>30 (51)</td>
<td>30 (49)</td>
</tr>
<tr>
<td><strong>Smoking status — no. (%)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never smoked</td>
<td>21 (36)</td>
<td>24 (39)</td>
</tr>
<tr>
<td>Former smoker</td>
<td>18 (31)</td>
<td>19 (31)</td>
</tr>
<tr>
<td>Current smoker</td>
<td>20 (34)</td>
<td>18 (30)</td>
</tr>
<tr>
<td><strong>Family history of cardiovascular disease — no. (%)</strong></td>
<td>40 (68)</td>
<td>38 (62)</td>
</tr>
<tr>
<td><strong>Race or ethnic group — no. (%)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>41 (69)</td>
<td>41 (68)</td>
</tr>
<tr>
<td>Black</td>
<td>6 (10)</td>
<td>8 (13)</td>
</tr>
<tr>
<td>Asian</td>
<td>10 (17)</td>
<td>8 (13)</td>
</tr>
<tr>
<td>Other</td>
<td>2 (3)</td>
<td>4 (7)</td>
</tr>
<tr>
<td><strong>Body-mass index‡</strong></td>
<td>27.3±5.4</td>
<td>27.2±5.0</td>
</tr>
<tr>
<td><strong>Blood pressure — mm Hg</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic</td>
<td>124.5±17.4</td>
<td>125.6±15.9</td>
</tr>
<tr>
<td>Diastolic</td>
<td>79.2±11.1</td>
<td>80.5±11.4</td>
</tr>
<tr>
<td>Brachial-artery diameter — mm</td>
<td>3.6±0.6</td>
<td>3.7±0.8</td>
</tr>
<tr>
<td>Reactive hyperemia ratio§</td>
<td>8.9±4.1</td>
<td>8.8±4.2</td>
</tr>
<tr>
<td>Flow-mediated dilatation — %</td>
<td>6.5±2.6</td>
<td>7.1±4.2</td>
</tr>
<tr>
<td>Nitroglycerin-mediated dilatation — %¶</td>
<td>17.9±6.9</td>
<td>17.9±6.5</td>
</tr>
<tr>
<td><strong>CRP — mg/liter</strong></td>
<td>3.8±5.3</td>
<td>2.5±2.7</td>
</tr>
<tr>
<td><strong>Interleukin-6 — pg/ml</strong></td>
<td>2.1±3.9</td>
<td>2.4±5.4</td>
</tr>
<tr>
<td>Soluble E-selectin — ng/ml</td>
<td>20.3±13.6</td>
<td>19.6±14.0</td>
</tr>
<tr>
<td>t-PA — ng/ml</td>
<td>4.5±0.6</td>
<td>3.2±0.4</td>
</tr>
<tr>
<td>PAI-1 — ng/ml</td>
<td>21.39±1.8</td>
<td>21.5±1.5</td>
</tr>
<tr>
<td><strong>Von Willebrand factor — 1U/ml</strong></td>
<td>0.87±0.16</td>
<td>0.90±0.19</td>
</tr>
<tr>
<td>Leukocyte count — x10⁻⁹/liter</td>
<td>7.1±2.0</td>
<td>6.4±1.6</td>
</tr>
<tr>
<td>Cholesterol — mmol/liter</td>
<td>5.3±1.2</td>
<td>5.3±1.0</td>
</tr>
<tr>
<td>High-density lipoprotein</td>
<td>1.5±0.4</td>
<td>1.5±0.4</td>
</tr>
<tr>
<td>Low-density lipoprotein</td>
<td>3.2±1.0</td>
<td>3.1±0.9</td>
</tr>
<tr>
<td>Glucose — mmol/liter</td>
<td>5.1±0.6</td>
<td>5.1±0.8</td>
</tr>
<tr>
<td>Triglycerides — mmol/liter</td>
<td>1.5±1.5</td>
<td>1.4±1.0</td>
</tr>
</tbody>
</table>
Figure 2. Flow-Mediated Dilatation and Nitroglycerin-Mediated Dilatation during the 6-Month Study Period.
CONCLUSIONS

Intensive periodontal treatment resulted in acute, short-term systemic inflammation and endothelial dysfunction. However, 6 months after therapy, the benefits in oral health were associated with improvement in endothelial function.
ED treatment

• Treatment should target the underlying comorbidity that lead to ED

• Life style modification – diet, exercise, smoking cessation, weight reduction

• NO pathways – L-arginine, PDE-I

• Receptor and enzyme pathways – beta blockers, ACE-I, angiotensin receptor blockers, statins, aspirin
Secondary endothelial therapy

• Preserve the function of the already injured endothelium to delay progression of cardiovascular disease

• Statins, ACE-I, beta blockers, endothelin antagonists
<table>
<thead>
<tr>
<th>Factors associated with endothelial dysfunction</th>
<th>Interventions that improve endothelial function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased age</td>
<td>L-arginine</td>
</tr>
<tr>
<td>Male sex</td>
<td>Antioxidants</td>
</tr>
<tr>
<td>Family history of CHD</td>
<td>Smoking cessation</td>
</tr>
<tr>
<td>Smoking</td>
<td>Cholesterol lowering</td>
</tr>
<tr>
<td>Increased serum cholesterol</td>
<td>ACE inhibitors</td>
</tr>
<tr>
<td>Low serum HDL-cholesterol</td>
<td>Exercise</td>
</tr>
<tr>
<td>Hypertension</td>
<td>Mediterranean Diet</td>
</tr>
<tr>
<td>Increased serum homocysteine</td>
<td></td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td></td>
</tr>
<tr>
<td>Obesity</td>
<td></td>
</tr>
<tr>
<td>High-fat meal</td>
<td></td>
</tr>
</tbody>
</table>
Control questions

• What are the 3 main vasodilators?
• Define shear stress
• How oxidative stress leads to ED?
• Which functions of endothelium are dysbalanced / predominate in ED?
• What is the standard method for measurement of endothelial dysfunction?
• Endothelial barrier dysfunction in septic shock
  https://www.youtube.com/watch?v=yl6R_3Jrs_s
• NO and vasodilation
  https://www.youtube.com/watch?v=echVKswxTqQ
• Vascular endothelium
  http://www.authorstream.com/Presentation/nitinpuram-1516566-vascular-endothelium/
A short break
Venous insufficiency
Varices
Venous system of lower limbs

- Superficial
- Perforator
- Deep
Chronic venous disease

• Condition in which the veins cannot pump enough blood back to the heart
• 20% of Western population

• Varicose veins
• Chronic venous insufficiency
Chronic venous disease

• Causes:

• Deep vein thrombosis
• Arteriovenous fistula
• Phlebitis
• Thrombophilia
• Obesity
Varicose veins

- Dilated, often palpable, subcutaneous veins with **reversed blood flow**
- Mostly in legs
- 30% of population (18% men, 42% women)
- Risk factors: unknown, age, sex, pregnancy, obesity, family history
Pathogenesis

• **Reflux**

• Obstruction

• Varicose veins:
  • Increased amount of collagen
  • Decreased number of smooth muscle cells and elastin

• Disorganization of muscle components, disruption of elastin fibres and fibrosis

• **Weakness of vein wall** leads to dilatation and enlargement of the **valve ring** – the vein is unable to work properly - **reflux**
Pathogenesis

• **Descending** theory – the process starts proximally and expands distal

• **Ascending** theory – tributaries become dilated and incompetent and only thereafter the main trunks and junctions
Pathogenesis

• **Obstruction**

• **Acute** obstruction occurs in deep vein thrombosis

• **Chronic** obstruction caused by post-thrombotic changes – stenosis, occlusion, rigidity of vein wall

• Obstruction + reflux – in 55% of symptomatic patients
Figure 4. Contrasting Effects of Steady, Laminar Shear Stress (Panel A) and Turbulent or Reversing Shear Stress (Panel B) on Vessel Walls.
Evaluation

- **Clinical features**: swelling, stasis, skin changes, ulceration
- **Symptoms**: limb pain, itching, restless legs, nocturnal leg cramps, heaviness, discomfort

- Pain
Pain

• Assessed by **visual-analogue scale**, type and frequency of analgesic use
• Absent in 20% patients
• The only feature in 10% patients
• Is relieved by **leg elevation, support stockings, walking**
CEAP classification

- Clinical
- Etiologic
- Anatomical
- Pathophysiological

CVI = C₃ - C₆
**Figure 1. Clinical Manifestations of Chronic Venous Disease.**

Telangiectases (clinical, etiologic, anatomical, and pathophysiological [CEAP] class C1) are shown in Panel A, varicose veins (CEAP class C2) in Panel B, pigmentation (CEAP class C3) in Panel C, and active ulceration (CEAP class C4) in Panel D.
# CEAP

<table>
<thead>
<tr>
<th>Clinical class</th>
<th>Anatomy</th>
<th>Pathology</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₀</td>
<td>Aₛ</td>
<td>Pₛ</td>
</tr>
<tr>
<td></td>
<td>No venous disease</td>
<td>Superficial Veins</td>
</tr>
<tr>
<td>C₁</td>
<td>Aₒ</td>
<td>Pₒ</td>
</tr>
<tr>
<td>Spider Angioma</td>
<td>Deep Veins</td>
<td>Obstruction</td>
</tr>
<tr>
<td>C₂</td>
<td>Aₚ</td>
<td>Pₓₒ</td>
</tr>
<tr>
<td>Varicose veins</td>
<td>Perforating Veins</td>
<td>Reflux &amp; obstruction</td>
</tr>
<tr>
<td>C₃</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Edema of venous etiology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C₄</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyperpigmentation, Dermatitis, Lipodermatosclerosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C₅</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Healed ulceration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C₆</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active ulceration</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Etiology</th>
</tr>
</thead>
<tbody>
<tr>
<td>E₉</td>
</tr>
<tr>
<td>Congenital</td>
</tr>
<tr>
<td>Eₚ</td>
</tr>
<tr>
<td>Primary</td>
</tr>
<tr>
<td>E₈</td>
</tr>
<tr>
<td>Secondary</td>
</tr>
</tbody>
</table>
### Table 2. Venous Clinical Severity Score.*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Score 0</th>
<th>Score 1 (mild)</th>
<th>Score 2 (moderate)</th>
<th>Score 3 (severe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain</td>
<td>None</td>
<td>Occasional; no use of analgesics</td>
<td>Daily; occasional use of non-narcotic analgesics</td>
<td>Constant use of narcotic analgesics</td>
</tr>
<tr>
<td>Varicose veins</td>
<td>None</td>
<td>Few, scattered</td>
<td>Multiple</td>
<td>Extensive</td>
</tr>
<tr>
<td>Edema</td>
<td>None</td>
<td>Evening, ankle only</td>
<td>Afternoon, above ankle</td>
<td>Morning above ankle</td>
</tr>
<tr>
<td>Hyperpigmentation</td>
<td>None</td>
<td>Limited</td>
<td>Diffuse over lower third of leg</td>
<td>Wide distribution</td>
</tr>
<tr>
<td>Inflammation and cellulitis</td>
<td>None</td>
<td>Mild</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>Induration</td>
<td>None</td>
<td>Focal</td>
<td>Less than lower third of leg</td>
<td>Entire lower third of leg or more</td>
</tr>
<tr>
<td>Active ulcers — no.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>&gt;2</td>
</tr>
<tr>
<td>Duration of active ulceration — mo</td>
<td>None</td>
<td>&lt;3</td>
<td>3–12</td>
<td>Not healed at &gt;12</td>
</tr>
<tr>
<td>Diameter of active ulcer — cm</td>
<td>None</td>
<td>&lt;2</td>
<td>2–6</td>
<td>&gt;6</td>
</tr>
<tr>
<td>Use of stockings</td>
<td>None</td>
<td>Occasional</td>
<td>Most days</td>
<td>Constant</td>
</tr>
</tbody>
</table>

* An aggregate score for the limb is calculated by adding the individual component scores. The range of the total score is 0 to 30.
Imaging

• Duplex ultrasound scan
Complications

• Deep vein thrombosis
• Skin changes
• Thrombophlebitis – thrombus in superficial vein
• Leg ulcers (3% patients)
• Bleeding
Treatment

- Goals:
  - Alleviate symptoms
  - Prevent severe complications (ulcers)

- 1. Endothermal ablation of the saphenous vein – burn the vein from inside (radiofrequency or laser)
- 2. Foam sclerotherapy
- 3. Surgery
- 4. Compression hosiery (only if no other intervention is suitable)
Advice

• Weight loss
• Light to moderate physical activity
• Avoid factors that make symptoms worse
• When and where to seek further medical help
BOX 1. WHEN TO REFER TO A VASCULAR SERVICE

Patients should be referred to the vascular service if any of the following are observed:
- Bleeding from the varicose veins – in this situation, the referral must be made immediately
- Symptomatic primary or symptomatic recurrent varicose veins
- Lower-limb skin changes, such as pigmentation or eczema, thought to be caused by chronic venous insufficiency
- Superficial vein thrombosis (characterised by the appearance of hard, painful veins) and suspected venous incompetence
- A venous leg ulcer (a break in the skin below the knee that has not healed within two weeks)
- A healed venous leg ulcer
Treatment in pregnancy

• Pregnancy can exacerbate symptoms of varicose veins and cause new ones

• **No intervention** in pregnancy (increases risk of thrombosis)

• Compression hosiery should be used
Flowchart ‘Management of chronic venous disease’

Patient

History (QoL)

Clinical exam (VCSS, CEAP) + DUPLEX of the superficial and deep venous system

C0-C5
Superficial vein pathology

- Saphenous incompetence
  - Thermal ablation
  - Non-thermal ablation
  - Conservative

- Tributary incompetence
  - Sclerotherapy
  - Foam sclerotherapy
  - Phlebectomy
  - Conservative

C0-C5
Deep vein pathology

- Consider Rx of superficial pathology first if also present

Vascular malformations

Multidisciplinary approach

Deep Venous Obstruction

Deep Venous Incompetence

Conservative
- Stenting
- Endophlebectomy
- AV fistula

Conservative
- Valvuloplasty
- Valve/ Vein transposition
- Neovalve
Control questions

• Two mechanisms of CVI
• What does CEAP mean?
• What is the link between CVI and ED?
• Diagnostic methods
• How to know the most up-to-date methods of therapy?
• romangardlik@gmail.com