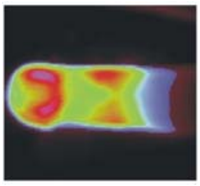
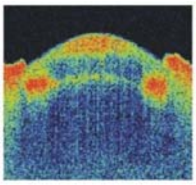
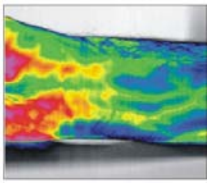
Applied Optoelectronics in Medicine

Aplikovaná optoelektronika v lékařství

Interdisciplinary course at the CTU Prague (P317APL-E, W, 4 credits)



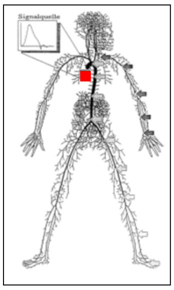



6. Biophysics of blood circulation, modeling haemodynamics
6. Biofyzikální základy krevního oběhu, modelování hemodynamiky

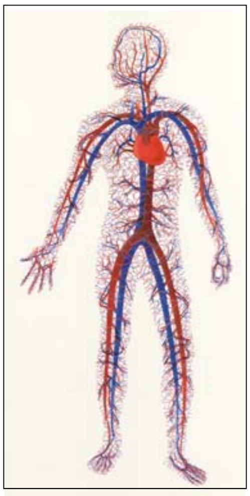
Learning aims of the sixth AOM lecture

- Anatomical basic informations, blood pressure compartements
- Biophysics of blood circulation
- In memoriam: Christian DOPPLER and his effect
- Modeling and simulation of human hemodynamics using the electrical line theory



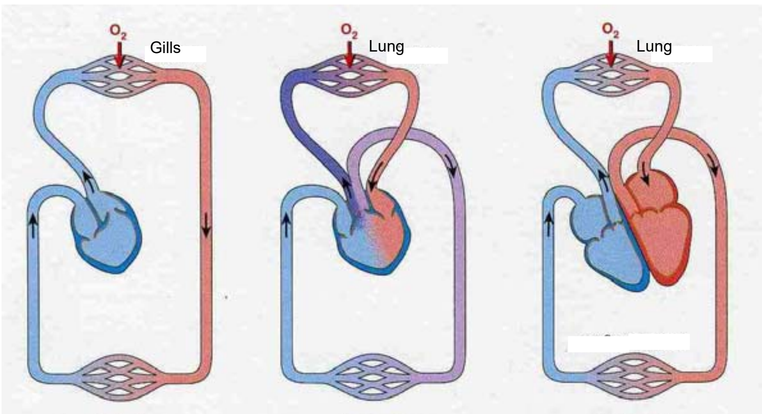



Basics of human hemodynamics
A gigantic transportation system



Heart:	high effective pump, > 2 Gigajoule/life
Vessels:	pipeline tree without losses >100.000 km
Blood:	5 - 6 liters, transportation medium for oxygen and metabolic products

Basics of human hemodynamics
Evolution steps from cardio-vascular system



Basics of human hemodynamics

A human cardio-vascular system

A heart is divided into a double pumping system for the small lung and the big body blood circulatory system.

Fully oxygenated blood in the high pressure vessels (aorta and big arteries) is light red Coloured (see figure), the oxygen reduced blood in the (low pressure) venous system is visualized with violet-blue colour.

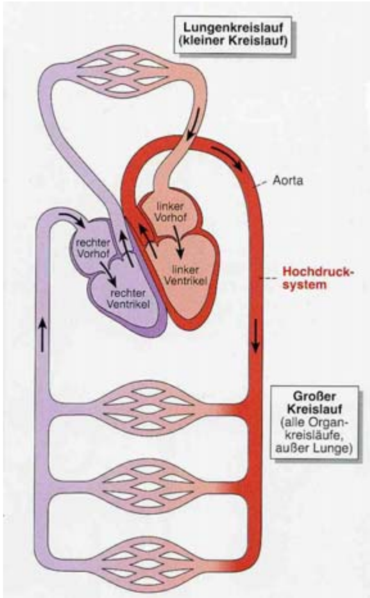
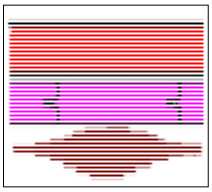
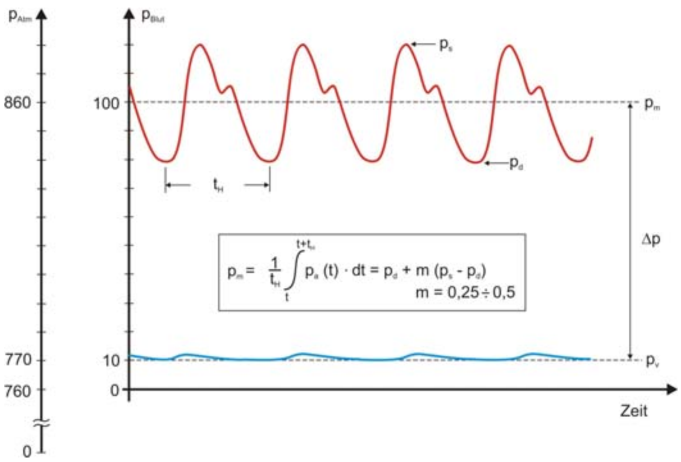


Figure: Golenhofer, Physiologie. Urban & Schwarzenberg 1997

Basics of human hemodynamics

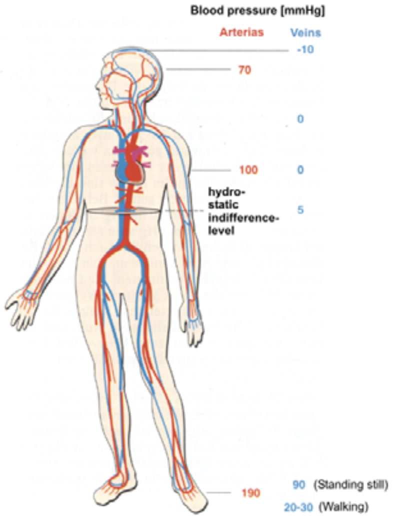
Blood pressure terms in human cardio-vascular system in horizontal position

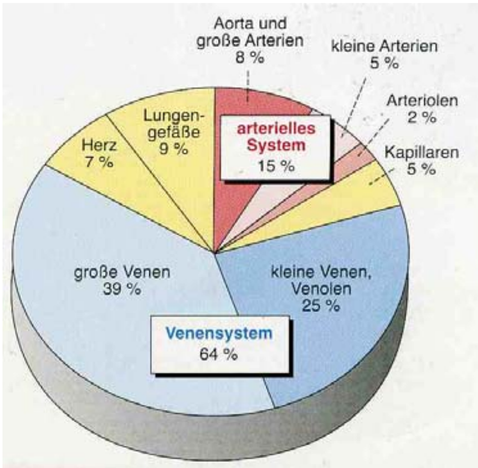




Basics of human hemodynamics

In vertical body position hydrostatic pressure components must be added to the physiological values in horizontal position (1m blood upright is conform to 80 mmHg pressure)

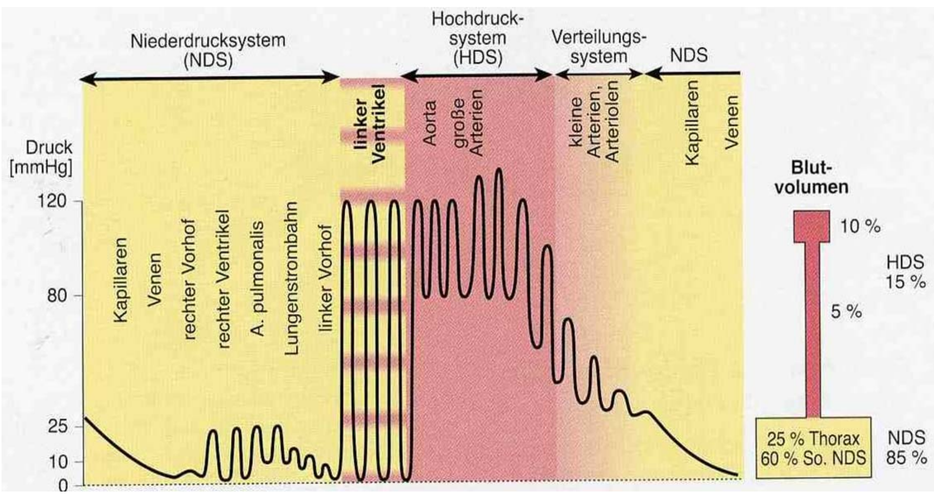




Figures: Golenhofer, Physiologie. Urban & Schwarzenberg 1997

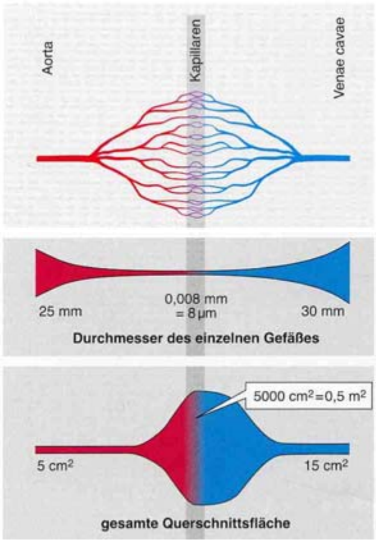
Basics of human hemodynamics

On the way with a pressure sensor through the cardio-vascular system



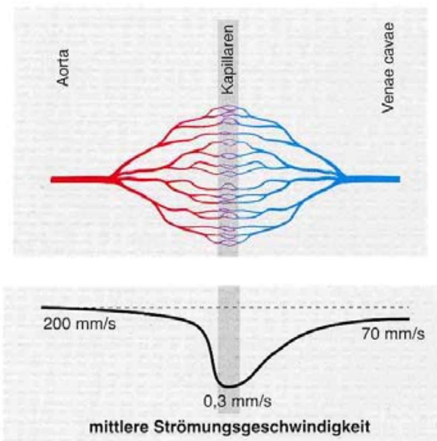
Basics of human hemodynamics

On the way with a video camera sensor
through the cardio-vascular system



Basics of human hemodynamics

On the way with a blood flow sensor through the cardio-vascular system



Basics of human hemodynamics

Non linear, time variant correlation between blood pressure and blood volume (in aorta, classified for different age groups)

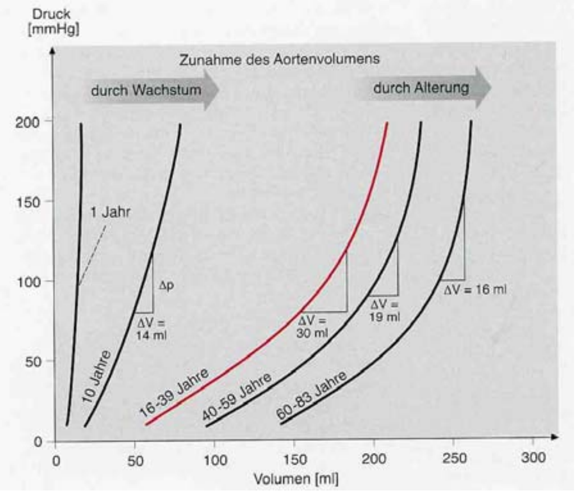
Some criterions for the vascular extensibility are

- Compliance C
- Volume elasticity module k
- Pulse wave velocity cp

$$C = \frac{\Delta V}{\Delta p}$$

$$k = \frac{\Delta p \cdot V}{\Delta V}$$

$$c_p = \sqrt{\frac{k}{\rho}}$$



Basics of human hemodynamics

Numerical example: value of mechanical work of the left heart

$$W = W_p + W_b = \Delta p \cdot \Delta V + \frac{1}{2} \rho \cdot v^2 \cdot \Delta V$$

Basics of human hemodynamics

Fundamental laws of blood circulation

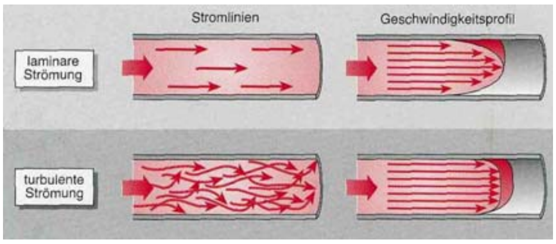
Mean blood volume flow $\dot{V} = \frac{\Delta V}{\Delta t}$

and

vascular resistance $R = \frac{\Delta p}{\dot{V}}$

HAGEN-POISEULLE law
(for laminar blood flow):

$$\dot{V} = \frac{\pi \cdot r^4}{8\eta \cdot \Delta l} \cdot \Delta p$$



REYNOLD Number
(threshold between laminar
and blood flow):

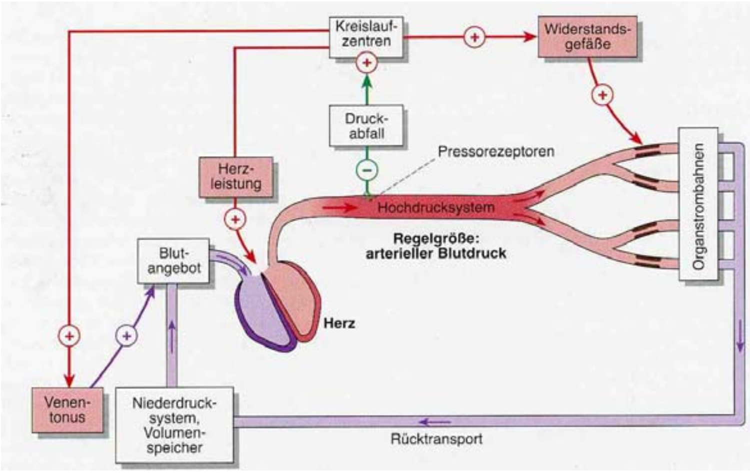
$$R_e = \frac{\rho \cdot v \cdot D}{\eta}$$

LAPLACE law
(for vascular wall densibility): $\sigma_T = \frac{p \cdot r}{d}$

Figure: Golenhofer, Physiologie. Urban & Schwarzenberg 1997

Basics of human hemodynamics

An example of an automatic “endogenous” blood pressure control using body's own “human pressure sensors” and regulation networks



Basics of human hemodynamics:

An example of an “endogenous” blood volume control using HMV parameter (heart minute volume)

- at rest *(left)*
- at maximal body power *(middle)*
- at maximal temperature exposition *(right)*

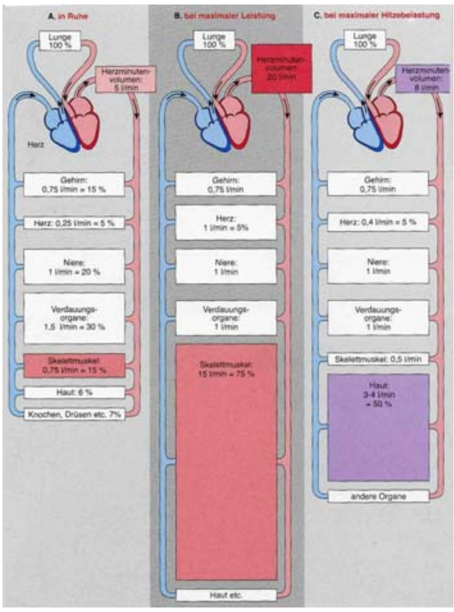


Figure: Golenhofer, Physiologie. Urban & Schwarzenberg 1997

Basics of human hemodynamics:

Most important applications of biosensors by monitoring of cardio-vascular function

1) Functional monitoring of blood pressure (venous or arterial)

2) Functional monitoring of blood flow (venous or arterial)

3) Functional monitoring of blood volume (venous or arterial)

First blood pressure measurement – historical remarks

For a long time observations of blood pressure changes in the vascular system in living beings had been investigated for scientific purposes.

Chinese practitioners for example already routinely examined the palpable pulsation of radial arteries as a means of diagnosing the physiological status.

In 1726 the reverence Stephen HALES (1677 - 1761) was the firs to observe the magnitude of the arterial blood pressure and it's oscillation - in an invasive manner.

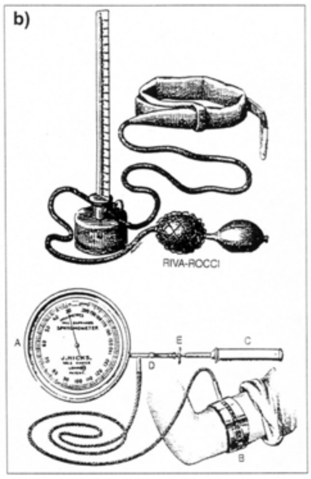
Invasive blood pressure measurement today

… nearly the same procedure as 280 years ago.

Noninvasive measurement of arterial blood pressure – historical remarks

First experimental studies:

- Karl VIERORDT (1818 - 1884)
- Samuel Siegfried von BASCH (1837 - 1905)
- **Scipione RIVA-ROCCI (1863 - 1937)**



Sphygmomanometer from Riva-Rocci, model 1896.
The first arm-encircling blood pressure cuff
(sphygmos=pulse; metron=gauge)

Non-invasive measurement of arterial blood pressure – historical remarks

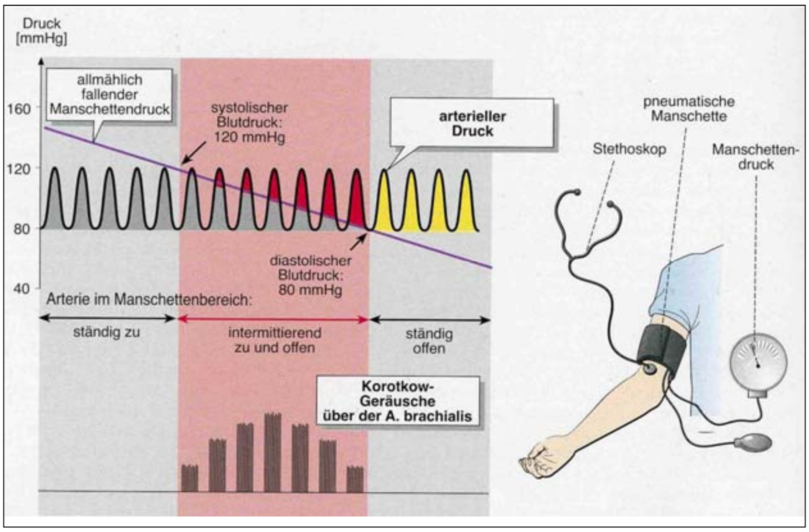
First experimental studies:

In 1905 the russian military physician **Nikolai Sergejewitsch KOROTKOW** (1874 - 1920) improved the Riva-Rocci method by using a stethoscope instead of a finger for the assessment of arterial blood pressure values

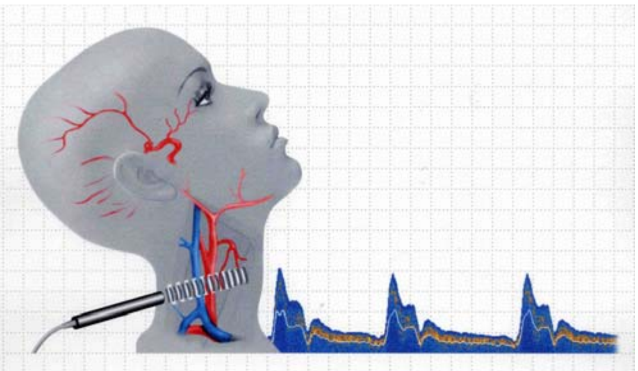
Remember:

*Korotkow sound are caused by external compression of the artery by the cuff. The (silent) **laminar** blood flow is transformed to a **turbulent** (audible) flow, if the occlusion pressure in the cuff is between p_{syst} and p_{diast} .*

Non-invasive measurement of arterial blood pressure

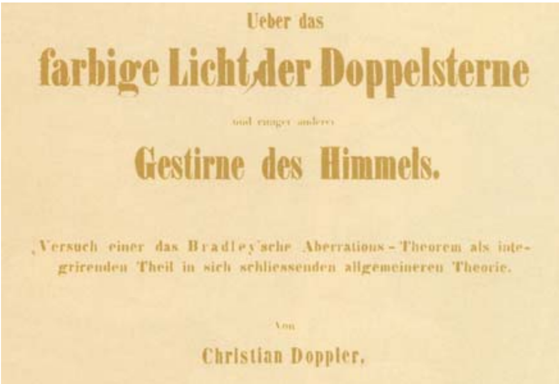


Non-invasive monitoring of arterial and/or venous blood flow
Ultrasound Doppler systems



Excurse

On 25th May 1842, Christian DOPPLER - Professor of Mathematics and Practical Geometry of the Prague Polytechnic (now Czech Technical University) - presented his paper “On the colored light of the double stars and certain other stars of the heavens” in a session of Natural Sciences of the Royal Bohemian Society of Sciences. Here, the famous DOPPLER principle was formulated for the first time.


Ueber das

farbige Licht der Doppelsterne

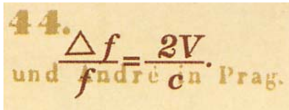
und einiger andern

Gestirne des Himmels.

Versuch einer das Bradley'sche Aberrations-Theorem als integrirenden Theil in sich schliessenden allgemeineren Theorie.

Von

Christian Doppler.



DOPPLER´s theory applied in daily use ...

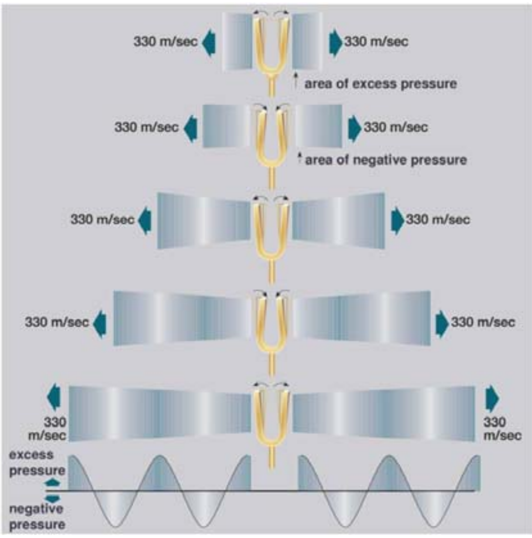
DOPPLER´s theory applied in daily use ...

2. Anhörung zur Verkehrsordnungswidrigkeitenanzeige

Nach § 55 OWiG wird Ihnen hiermit Gelegenheit gegeben, zu dem Vorwurf Stellung zu nehmen. Es steht Ihnen frei , sich zu der Beschuldigung zu äußern oder nicht zur Sache auszusagen.
Sie sind aber in jedem Fall - auch wenn Sie die Ordnungswidrigkeit nicht begangen haben - verpflichtet, die Fragen zur Person (Nr. 1) vollständig und richtig zu beantworten. Die Verletzung dieser Pflicht ist nach § 111 OWiG mit Geld bedroht. Der ausgefüllte Fragebogen ist innerhalb einer Woche ab Zugang des Schreibens zurückzusenden.
Sofern Sie sich nicht zur Beschuldigung äußern, kann **ohne Rückäußerung der Verwaltungsbehörde** ein Bußgeldbescheid erlassen werden. Der Erlaß eines Bußgeldbescheides ist mit Kosten (Gebühren und Auslagen verbunden).
Wenn Sie die Ordnungswidrigkeit nicht begangen haben, teilen Sie bitte **innerhalb einer Woche** ab Zugang dieses Schreibens neben Ihren Personalien zusätzlich die Personalien des Verantwortlichen unter den Angaben (Nr.2) mit; hierzu sind Sie nicht verpflichtet.

Hochachtungsvoll
Im Auftrag

Acoustic waves



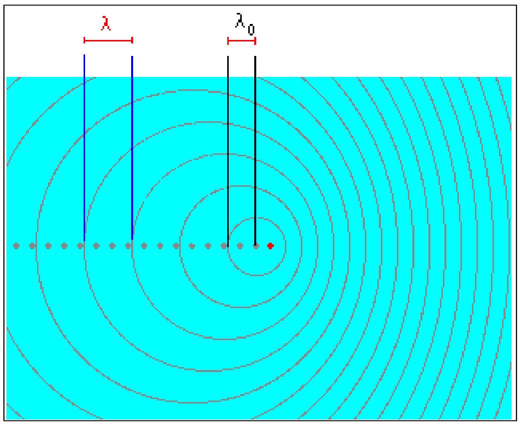
Generation of a sound wave by a tuning fork in the form cyclical pressure differences in the air

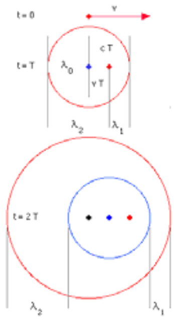
Remember:

Acoustic waves are longitudinal waves, oscillating in the direction of propagation (in contrast to transversal EM waves, which oscillate perpendicular to the direction of propagation)

DOPPLER´s theory

$$\Delta f = \frac{2 \cdot f \cdot \cos\Theta}{c}$$





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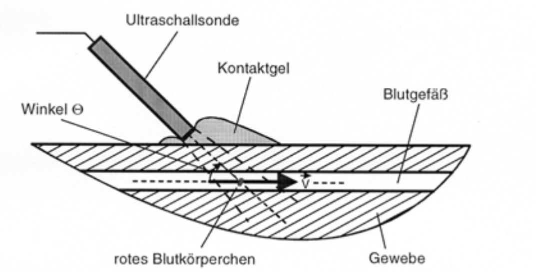
(Source: www.jgiessen.de)

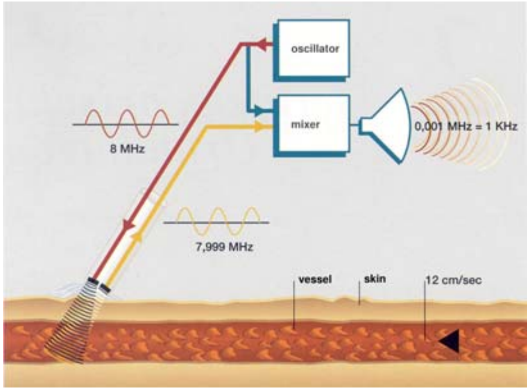
Studies of peripheral hemodynamics using simplest ultrasound Doppler technique



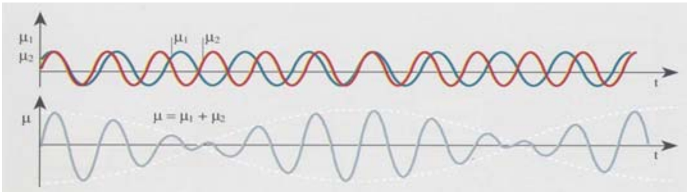
$$\Delta f = \frac{2 \cdot \cos\Theta}{c} \cdot f_0 \cdot \vec{v}$$

f_0 ... Sendefrequenz
β ... Winkel zw. Schallausbreitung u. Bewegungsrichtung der Teilchen
c ... Schallgeschwindigkeit im Gewebe
$\vec{v}$ ... Geschwindigkeit der Blutkörperchen

Unidirectional continuous wave Doppler device



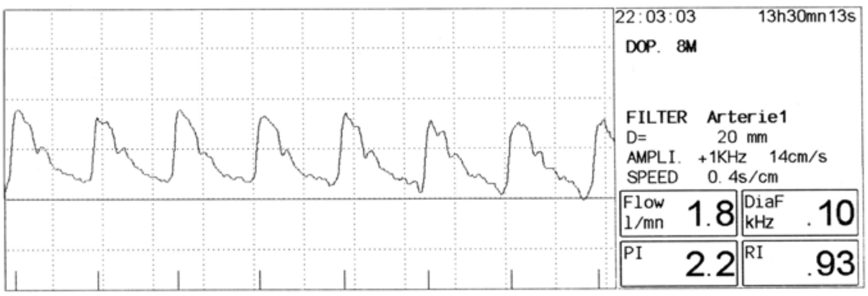
Phase superimposition in the mixer and creation of a Doppler frequency by summation and subtraction of the transmitted and received ultrasound frequency.



Example: Modern ultrasound device:

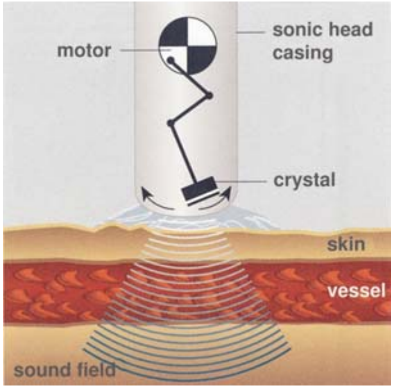
Example for: f_0 = 8 MHz
c_{Tissue} = 1350 m/s
v = 12 cm/s
Θ = 45°

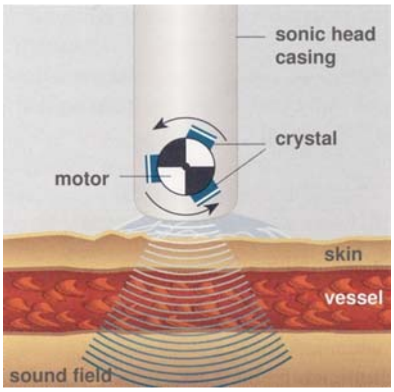
Doppler shift: **Δf = 1000 Hz**



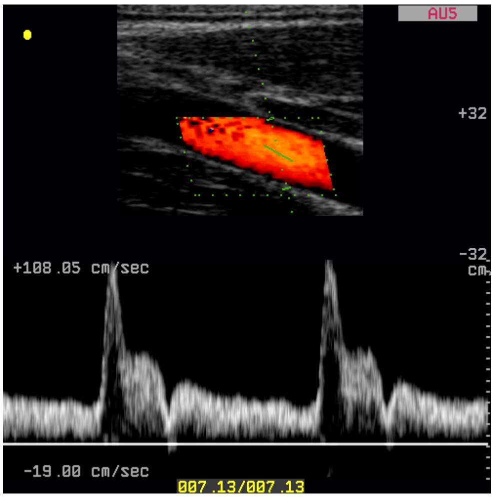
The ultrasound Duplex system

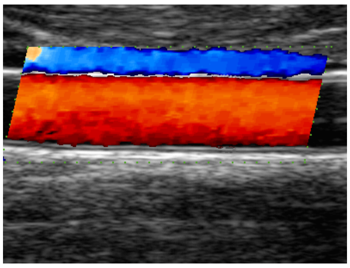
This system is a combination of an ultrasound section image and a pulsed Doppler device. So-called “mechanical sector scanners” were used for this purpose based on the principle, that a crystal (or a number of crystals) is moved backwards and forwards along a circular path (Wobbler, left picture) or is rotated (right picture).





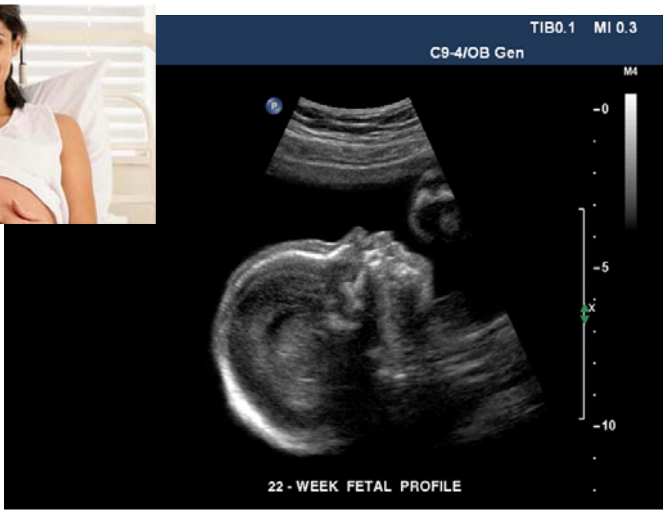
Example of a modern CFI system



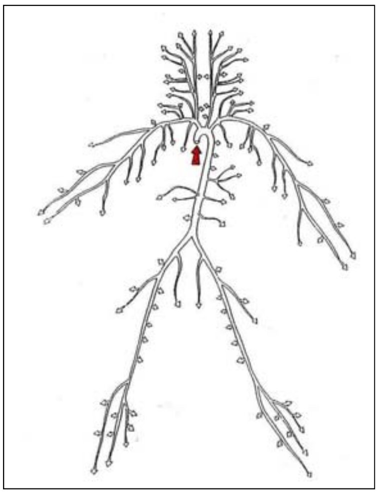


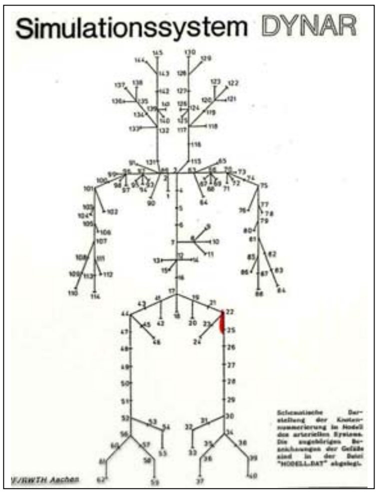
The ultrasound Duplex system in the prenatal medicine

… more than just
a pretty picture …

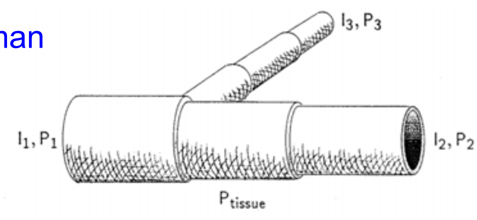


Modeling and simulation of human hemodynamics using the electrical line theory

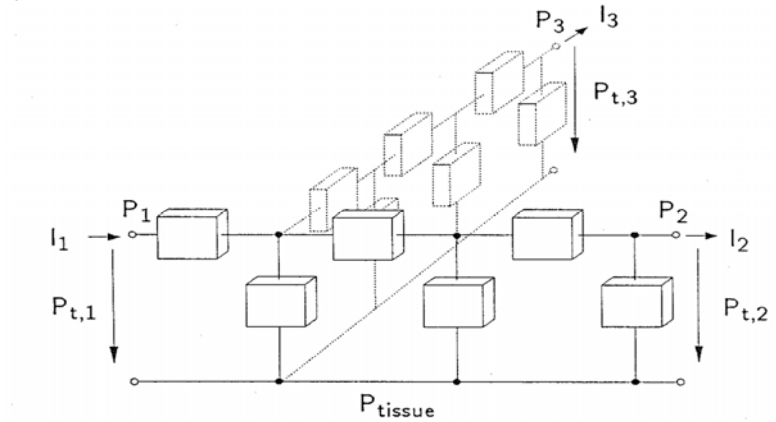




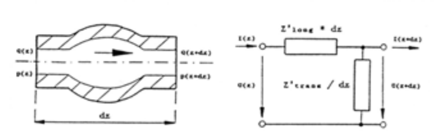
Modeling and simulation of human hemodynamics using the electrical line theory



Segmentation of the vascular tree in homogenous sections



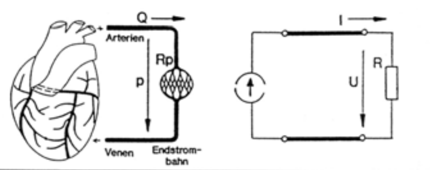
Modeling and simulation of human hemodynamics using the electrical line theory



$$-\frac{\partial P}{\partial z} = \underline{Z}'_{long} \cdot Q \qquad -\frac{\partial Q}{\partial z} = \frac{1}{\underline{Z}'_{trans}} \cdot P$$

$$\underline{Z}_L = \sqrt{\underline{Z}'_{long} \cdot \underline{Z}'_{trans}} \qquad \gamma = \sqrt{\frac{\underline{Z}'_{long}}{\underline{Z}'_{trans}}}$$

p .. Druck	[1 mmHg]	≙	U .. el. Spannung	[1 Volt]
Q .. Volumenstrom	[1 cm^3/s]	≙	I .. el. Strom	[1 Ampere]
Rp.. peripherer Widerstand	[1g/(cm^4•s)]	≙	R .. el. Widerstand	[7,502•10^{-4}Ω]



Modeling and simulation of human hemodynamics using the electrical line theory

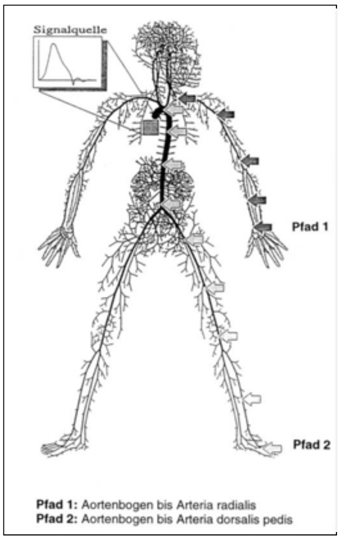
Parameters of the homogenous tree sections

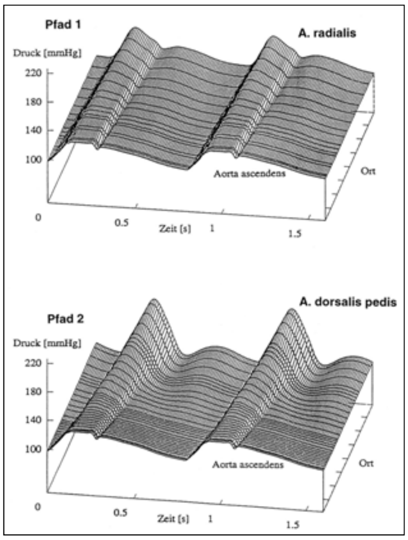
```
**************************************************************************
**                                                                      **
**      Die Datei MODELL.DAT enthaelt die Informationen ueber           **
**   die verschiedenen Leitungsabschnitte, unter Beruecksichtigung      **
**          der vorhandenen Daten ueber Elastizitaetsmoduln.            **
**                                                                      **
**************************************************************************
```

Knoten pro	Knoten dis	Bezeichnung der Arterie	Laenge [cm]	Radius [cm]	Dicke [cm]	E-Modul [1.E6*g/cm/s**2]	Leakage %
16	17	Aorta abdominalis	5.3	.85	.078	4.	
17	18	A.mesenterica inferior	5.	.16	.043	5.	2.505
17	19	A.iliaca communalis	5.8	.52	.076	8.	
19	20	A.iliaca interna	5.	.2	.04	25.	1.257
19	21	A.iliaca externa	8.3	.29	.055	10.	1.257
21	22	A.iliaca externa	6.1	.27	.053	10.	
22	23	A.profundus	6.3	.26	.052	25.	.754
23	24	A.profundus femoris	6.3	.19	.046	25.	.754
22	25	A.femoralis	6.35	.26	.052	13.	.501
25	26	A.femoralis	6.35	.25	.051	13.	.501
26	27	A.femoralis	6.35	.24	.05	13.	.501
27	28	A.femoralis	6.35	.23	.049	13.	.501
28	29	A.poplitea	9.4	.21	.048	16.	.501
29	30	A.poplitea	9.4	.2	.047	16.	
30	31	A.tibialis posterior	8.1	.24	.05	32.	.4

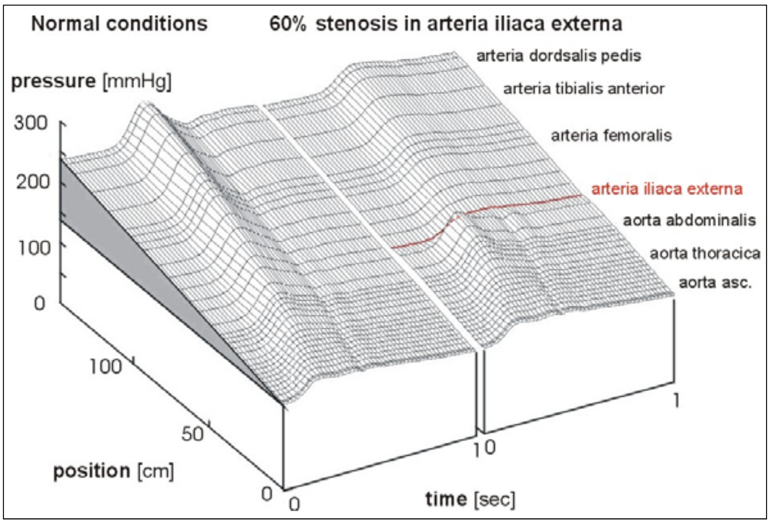
Typical simulation results of arterial pressure changes

in different vascular levels using virtual vascular tree, consisting from 4105 segments

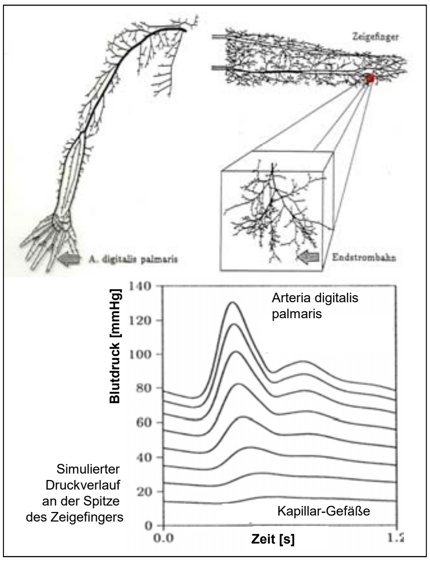


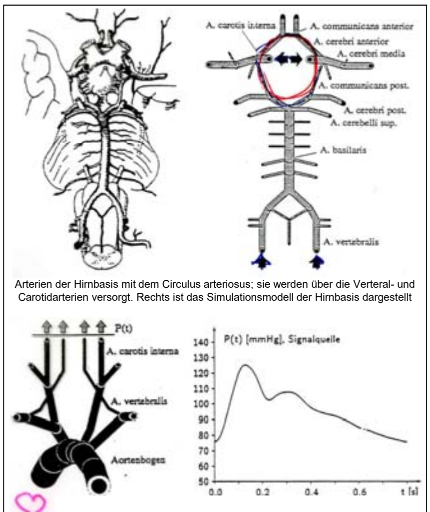


Arterial pressure propagation from aorta ascendens to arteria dorsalis pedis: Simulation of stenosis



M & S exampels: finger and brain perfusion

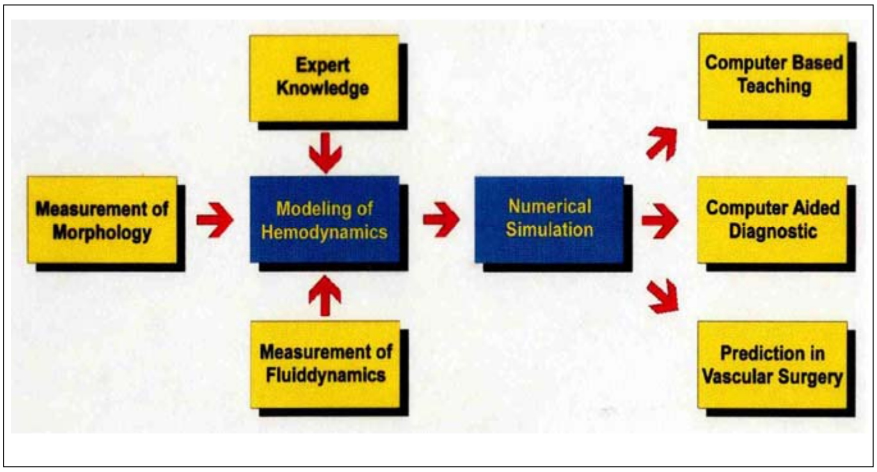




Arterien der Hirnbasis mit dem Circulus arteriosus; sie werden über die Verteral- und Carotidarterien versorgt. Rechts ist das Simulationsmodell der Hirnbasis dargestellt

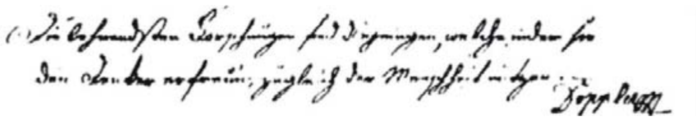
Die Blutversorgung des Gehirns erfolgt hauptsächlich über die beiden inneren Caroti-den und Vertebralarterien; der rechts dargestellte Druckverlauf wird im Modell als eingeprägt vorausgesetzt.

Modeling and simulation of human hemodynamics using the electrical line theory:
future aspects



Citát pro sestou přednášku / Quotation of the lecture 6:

"The most rewarding researches are those which, inasmuch as they are of joy to the thinker, are at the same time of benefit to mankind"



Christian DOPPLER (1803 - 1853)