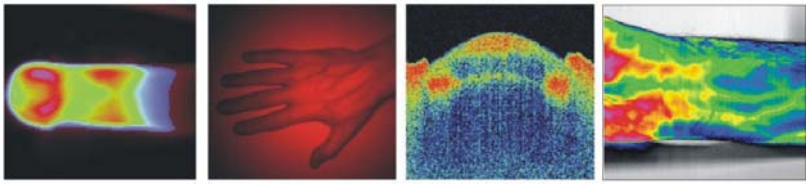
Applied Optoelectronics in Medicine

Aplikovaná optoelektronika v lékařství

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



7. Optoelectronic sensor concepts for vascular diagnostics – part I
7. Optoelektronické koncepty pro vaskulární diagnostiku – část I

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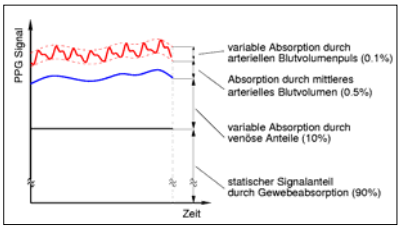
Learning aims of the seventh AOM lecture

- Basics of quantitative Photoplethysmography (PPG) for transcutaneous detection of dermal blood volume changes
- Standardized PPG tests for non-invasive assessment of peripheral venous hemodynamics:
  a) Muscle pump test and
  b) Venous occlusion test
- Alternative sensor concepts for blood volume studies in different compartments of human body



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Comparison of non-invasive tests of the vascular system with phlebography

A scale of 1-5, in order of ascending quality, has been used

Test	Accuracy: Thigh Obstr.	Thigh Insuff.	Calf Obstr.	Calf Insuff.	Portability	Training period	Cost	Quantitative results	Type
Doppler (CW)	1	4	1	4	5	Long	Low	1	Functional
Duplex ultrasound	5	5	4	5	3	Long	High	3	Anatomical & functional
Plethysmography									
segmental Air	4	4	3	4	3	Short	Medium	5	Functional
whole limb									
standard Photo	1	4	1	4	4	Short	Medium	3	Functional
calibrated	3	4	2	4	4			5	
Foot volumetry	3	4	3	4	0	Short	Medium	5	Functional
Impedance	4	2	2	1	3	Short	Medium	4	Functional
Strain gauge	4	2	2	1	3	Short	Medium	4	Functional
Phleborheography	4	2	2	1	3	Short	Medium	0	Functional
Phlebography	5	4	4	4	0	Long	High*	2	Anatomical

From: THE NEWS, Phlebology edition, No. 31,k Sept. 1992

* = invasive

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Studies of peripheral hemodynamics using Photoplethysmography (PPG):

transcutaneous monitoring of venous and/or arterial blood volume changes in dermal vascular plexus.

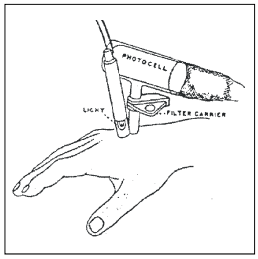
Milestones/Evolution steps:

1) 1938: first PPG system, created by Hertzman

2) 1979: LRR, first full portable PPG system

3) 1989: first quantitative, PC controlled PPG system with calibration software for each measurement

4) and today?
- "intelligent" OES strategies like Smart PPG
- camera based PPG Imager for spatial & time resolved skin perfusion studies



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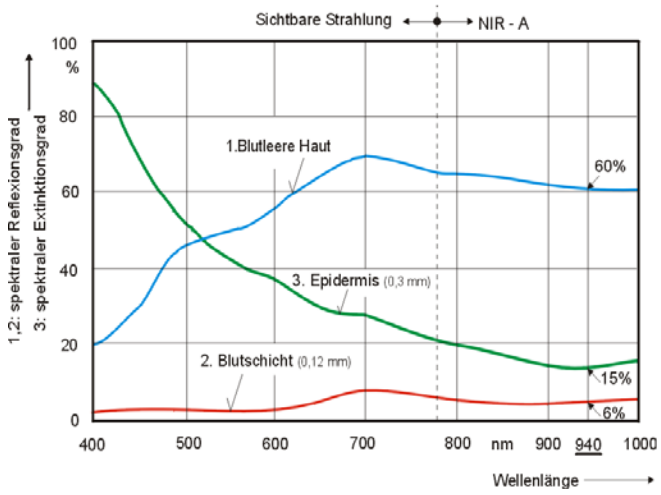
Discovery of the „optical windows“ through the skin in the 70ties l.c. at RWTH

allowed the construction of advanced optoelectronic sensors (optrodes) for non-invasive measurements of venous and/or arterial blood volume changes



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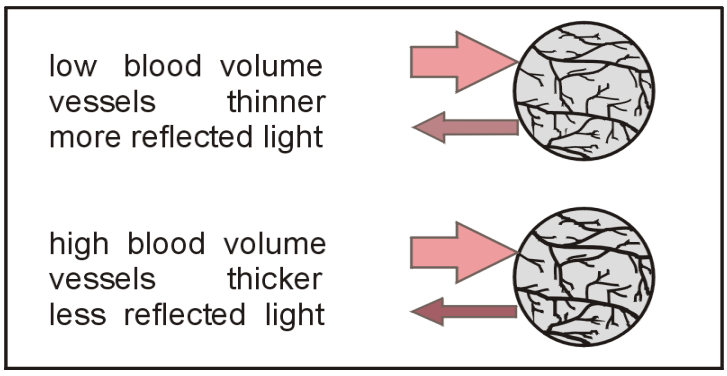
Fundamentals of Photoplethysmography (PPG) - one of the world wide well used methods for blood volume monitoring in dermal vascular network



Schematic visualisation of the correlation between the PPG signal and the blood volume changes in transilluminated vascular network under the sensor

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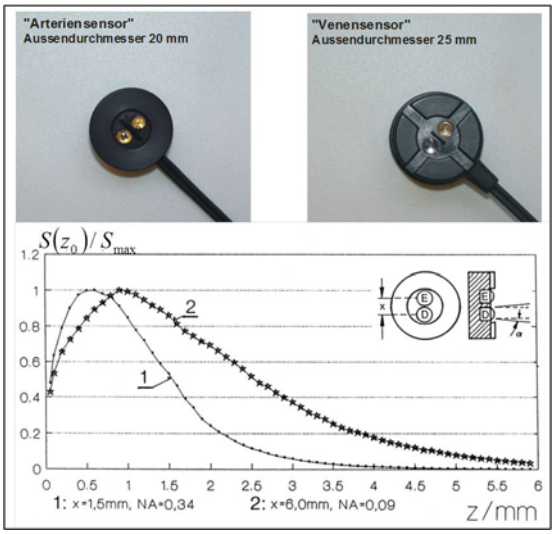
Fundamentals of Photoplethysmography (PPG) - one of the world wide well used methods for blood volume monitoring in dermal vascular network



$$S(z_0) = \frac{I(z_0)}{I_{ges}} = \frac{\int_{-y_{max}}^{y_{max}} \int_{-x_{max}}^{x_{max}} I_q(x,y,z_0) \cdot I_d(x,y,z_0) \cdot dx \cdot dy \cdot dz}{I_{ges}}$$

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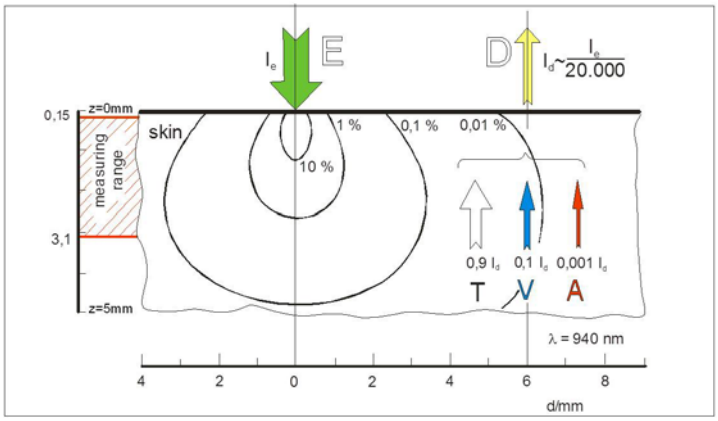
Fundamentals of Photoplethysmography (PPG) - one of the world wide well used methods for blood volume monitoring in dermal vascular network



Photon distribution in the skin and an estimation of the signal contents detected by the PPG sensor (T: tissue, V: venous signal, A: arterial signal). From 10^6 Photons injected to the skin in this model scenario only 50 were detected (-43 dB)

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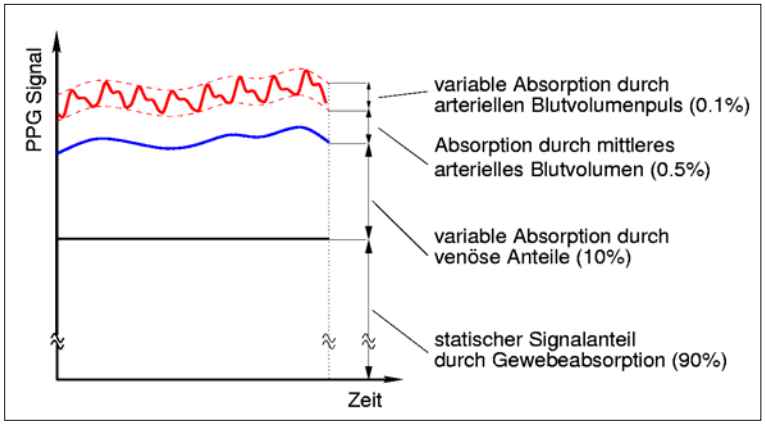
Fundamentals of Photoplethysmography (PPG) - one of the world wide well used methods for blood volume monitoring in dermal vascular network



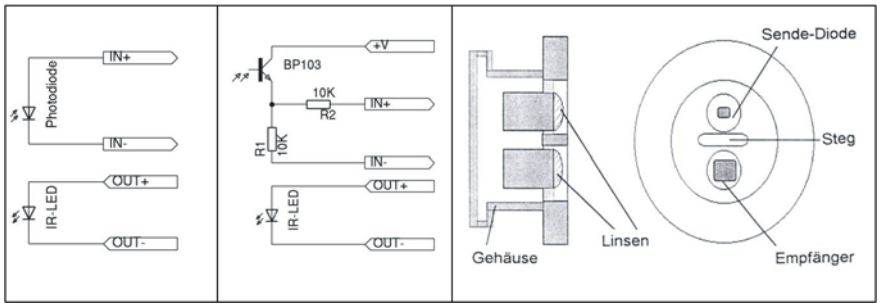
Time dependent visualisation of the typical PPG signal components

PPG measuring system „for beginners“

Optoelectronic components in the sensor

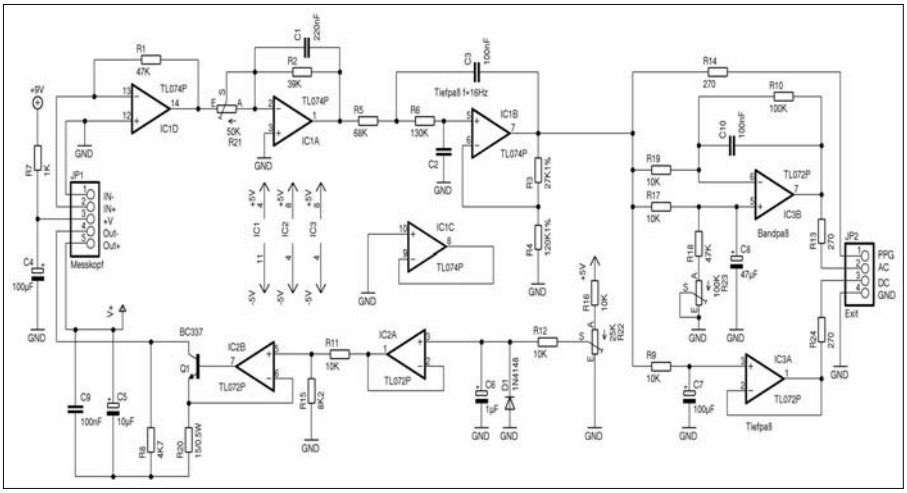
„Arterial sensor“: LD 242 as light source and BPW (photodiode) as light detector; both without focussing lenses.

„Venous sensor“: TIL31 as light source and TIL81 (phototransistor) as light detector; both with focussing lenses.

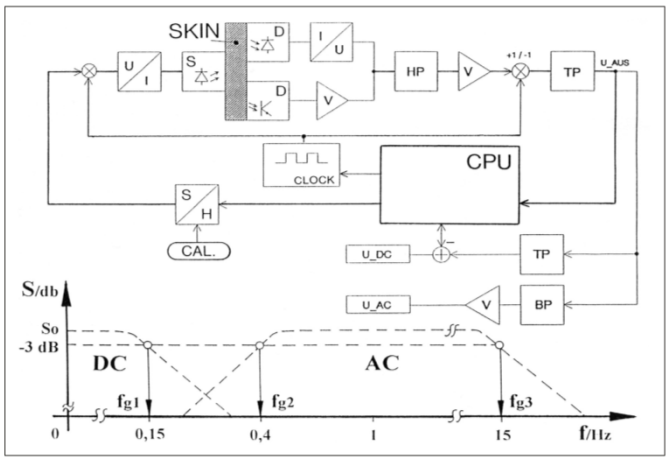


Possible sensor interfaces

PPG measuring system „for beginners“: schema of the electrical part

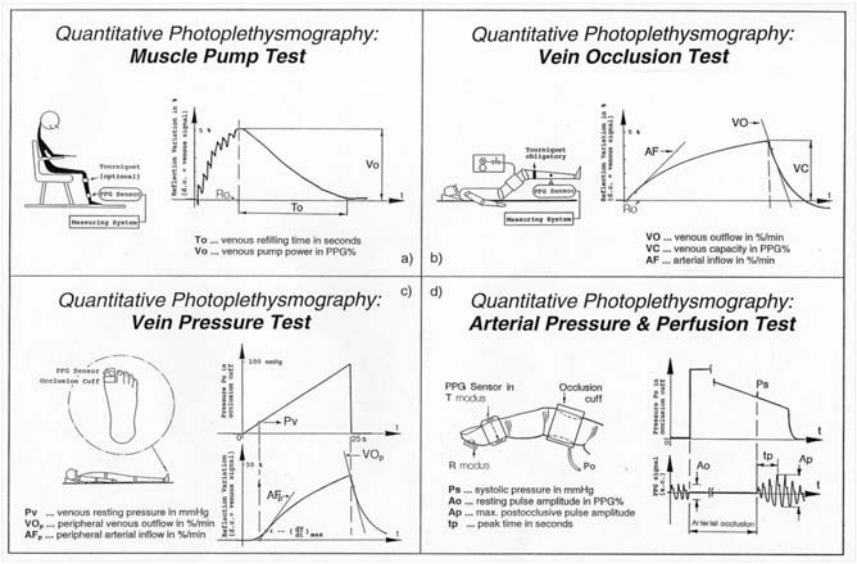


Fundamentals of Photoplethysmography (PPG) - one of the world wide well used methods for blood volume monitoring in dermal vascular network



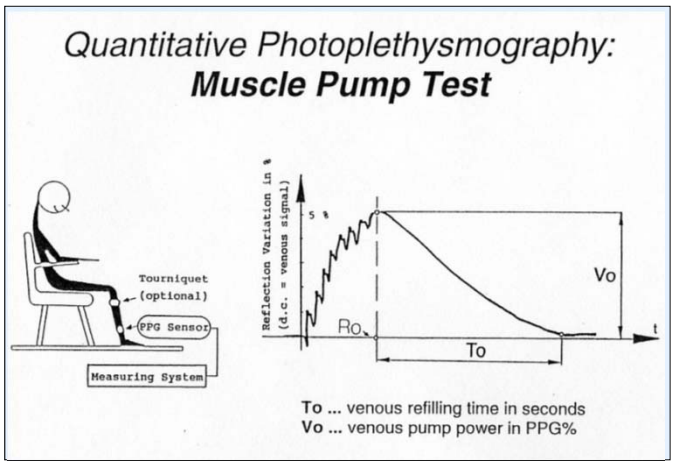
Block diagram of an µC aided PPG system (so called quantitative Photoplethysmography). In a closed loop the intensity of illumination will be adjusted to compensate individual optical transfer function of the skin.

Functional monitoring of vascular hemodynamics - standardized clinical PPG tests



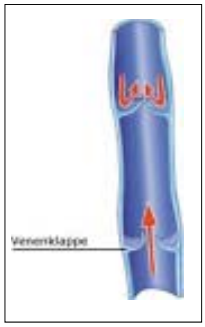
First and most used PPG test:

MPT for functional assessment of the global blood transport properties of the leg vein system during standardized exercise and for evaluating the efficiency of the calf pump

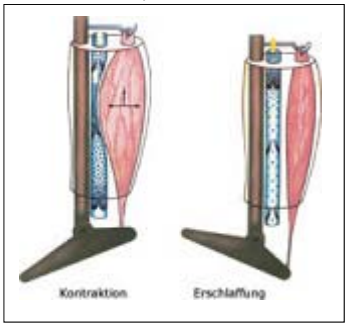


Wie funktioniert der venöse Rückstrom des Blutes beim Menschen?

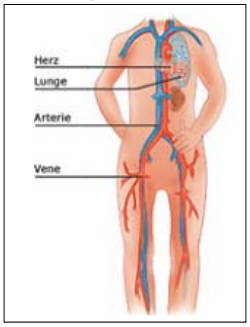
Venenklappen



Muskel-Venen-Pumpe



Thorax-Pumpe



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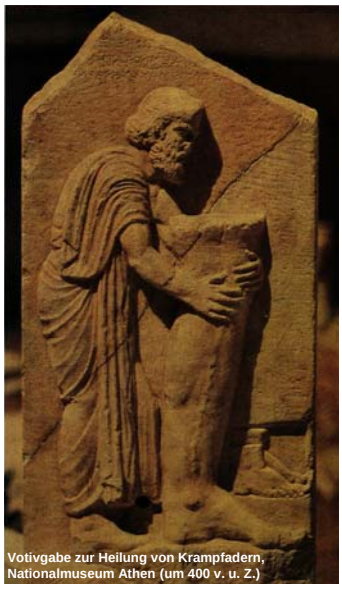

Votivgabe zur Heilung von Krampfadern, Nationalmuseum Athen (um 400 v. u. Z.)

Hl. Peregrinus, Votivbild in Mariazell, 1851

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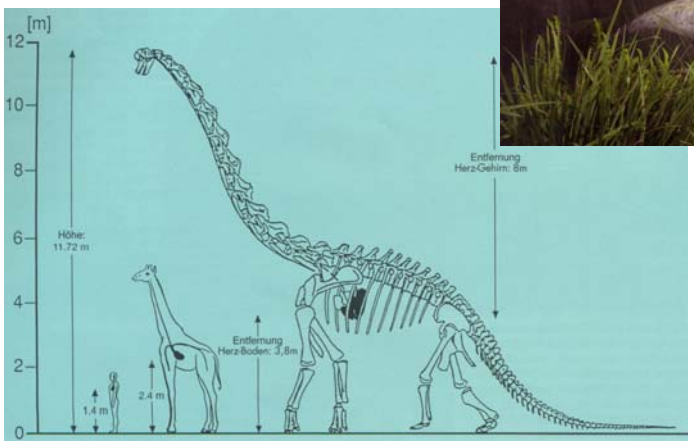
Why don't giraffes and other animals suffer from varicose veins like the human beings do?



Beispiel: **BRACHIOSAURIUS ***
Fundstücke aus der späten Jurazeit vor etwa 150 Mill. J. im Rahmen der deutschen Tendaguru-Expedition (1909-1913) in Tansania, Ostafrika.

K.M.: 100 T
B.V.: 3000 l
H.G.: 230 kg
S.V.: 15 l
BPM: 17
Psyst: 600 mmHg

*** Forschung 2-3/2001, DFG Bonn**

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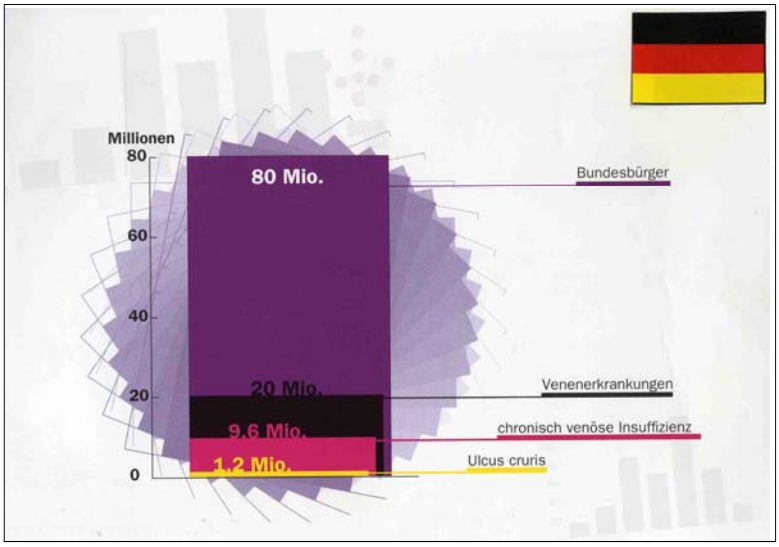
Zur Häufigkeit der Venenleiden...



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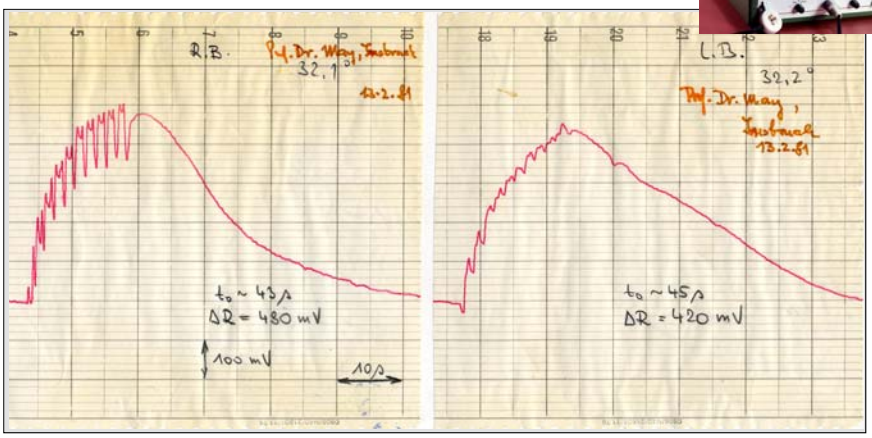
In Memoriam Robert May …



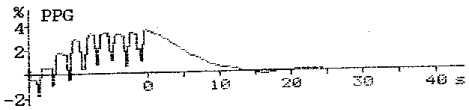
Klinisch eingeführte PPG-Geräte für funktionelle Venendiagnostik

Digital Photo-Plethysmography

Examination record: 7
(Version 4.0)

Name : .....
Date of birth : .....
Extremity : left ... right ...
Date, Time : .....
Diagnosis : .....
Remark : .....

Muscle Pump Test:



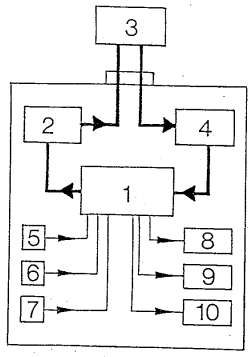
Quantitative parameters:

Venous refilling time	: To =	15	s
Half amplitude time	: Th =	5,5	s
Initial refilling time	: Ti =	11	s
Venous pump power	: Vo =	3,6	%/s
Venous pump work	: Fo =	23	%

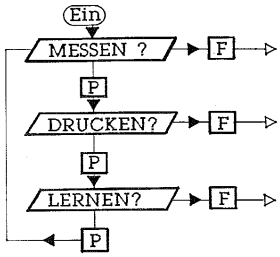
Weitere Vorteile der quantitativen Photoplethysmographen

Rechnergesteuerter Messablauf, einfache Bedienung, Datenspeicherung und -analyse

Blockschaltbild



Hauptmenü des D-PPG-Gerätes



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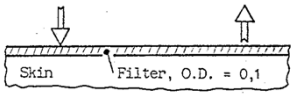
Selbsttest und automatische Signalkalibrierung durch Regelung des Sendestroms des PPG-Sensors

(succesive 8bit-Approximation).

Beispiel eines PPG-MPT-Protokolls:

Messwiderholung an der gleichen Hautstelle, jedoch mit einem Graufilter zwischen Sensor und Haut



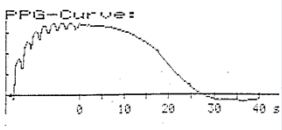

```
Sensor Output : P= 128   CPU: 4095
Sensor Output : P= 064   CPU: 2968
Sensor Output : P= 032   CPU: 1276
Sensor Output : P= 048   CPU: 2198
Sensor Output : P= 056   CPU: 2693
Sensor Output : P= 052   CPU: 2452
Sensor Output : P= 054   CPU: 2584
Sensor Output : P= 053   CPU: 2519

      Digital  Photo-
      Plethysmography

      Examinationrecord
   Measure  No. : 00915

Name                :.....................
Date of birth       :.....................
Extremity           :.....................
Date, Time          :.....................
Diagnosis           :.....................
Remark              :.....................

PPG-Curve:
```




```
Venous refilling time  : To = 30   s
Half amplitude time    : Th = 19   s
Venous drainage        : Vo =  6,7 %
Venous refilling area  : Fo = 135  %s
```

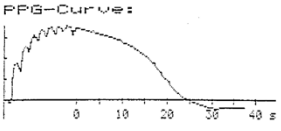
```
Sensor Output : P= 128   CPU: 4095
Sensor Output : P= 064   CPU: 1770
Sensor Output : P= 096   CPU: 2937
Sensor Output : P= 080   CPU: 2368
Sensor Output : P= 088   CPU: 2679
Sensor Output : P= 084   CPU: 2527
Sensor Output : P= 082   CPU: 2449
Sensor Output : P= 083   CPU: 2491

      Digital  Photo-
      Plethysmography

      Examinationrecord
   Measure  No. : 00916

Name                :.....................
Date of birth       :.....................
Extremity           :.....................
Date, Time          :.....................
Diagnosis           :.....................
Remark              :.....................

PPG-Curve:
```




```
Venous refilling time  : To = 28   s
Half amplitude time    : Th = 17   s
Venous drainage        : Vo =  6,9 %
Venous refilling area  : Fo = 120  %s
```

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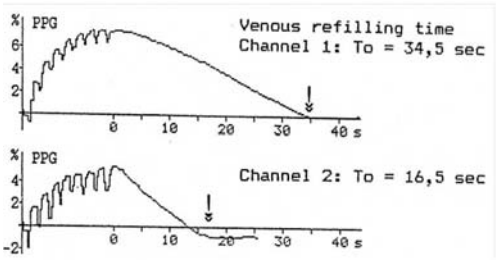
PPG muscle pump test



World wide standardized PPG degrees:

Normal	: To > 25 sec
PPG stage I	: To 24 to 20 sec
PPG stage II	: To 19 to 10 sec
PPG stage III	: To < 10 sec

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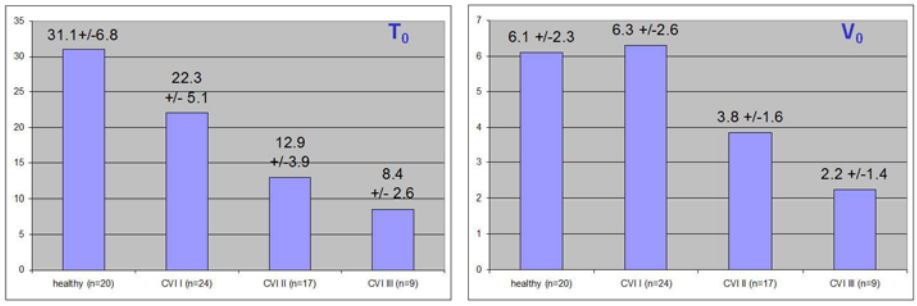
MPT parameter venous refilling time T_0 and venous drainage V_0 in relation to clinical severity of CVI *



* Blazek, V., Schultz-Ehrenburg, U.: Quantitative Photoplethysmography. VDI Verlag 1996

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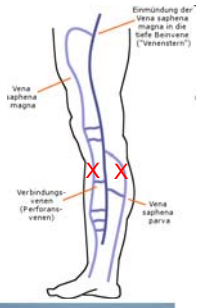
Quantitative Photoplethysmography: venous muscle pump test

Tourniquet test before invasive therapy (sclerotherapy or surgery)



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Quantitative Photoplethysmography: venous muscle pump test

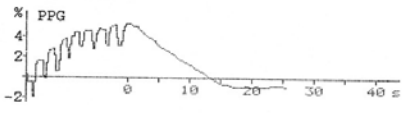
Tourniquet test before invasive therapy (sclerotherapy or surgery)

Digital Photo-Plethysmography

Examination record: 13
(Version 4.0)

Name : I.H.
Date of birth : 1962
Extremity : left X. right ...
Date, Time : ...
Diagnosis : ...
Remark : CVI + Bengal p.v. ...

Muscle Pump Test:



Quantitative parameters:

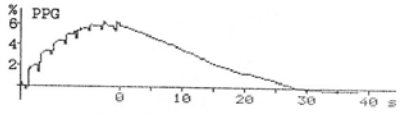
Venous refilling time	: To =	16	s
Half amplitude time	: Th =	7	s
Initial refilling time	: Ti =	14	s
Venous pump power	: Vo =	5,2	%
Venous pump work	: Fo =	41	%s

Digital Photo-Plethysmography

Examination record: 20
(Version 4.0)

Name : I.H.
Date of birth : 1962
Extremity : left X. right ...
Date, Time : ...
Diagnosis : ...
Remark : Tourniquet left ...

Muscle Pump Test:



Quantitative parameters:

Venous refilling time	: To =	29	s
Half amplitude time	: Th =	13	s
Initial refilling time	: Ti =	28	s
Venous pump power	: Vo =	6,0	%
Venous pump work	: Fo =	83	%s

Patient with improvable CVI. Measurements without (left) ant with tourniquet (right)

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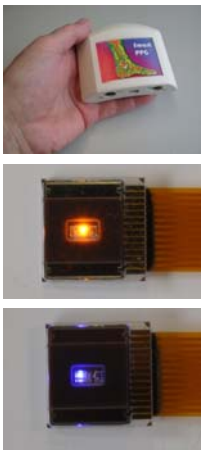
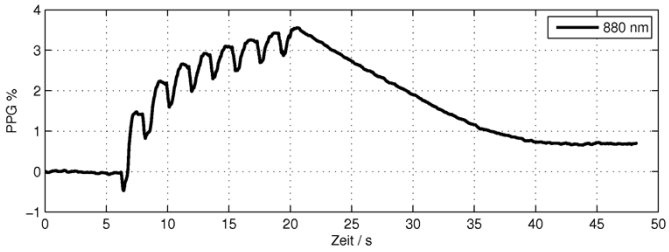
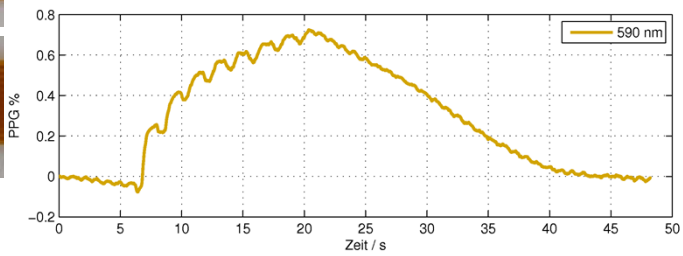
Example: Multi-wavelength venous recordings using “MedIT smart PPG”







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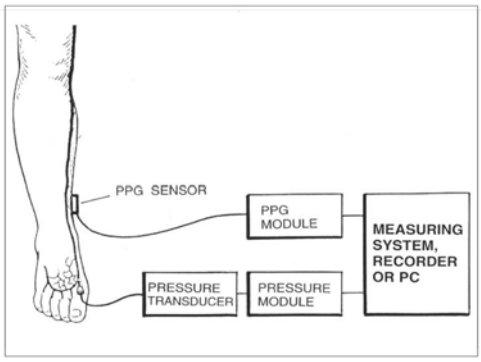
PPG and invasive vein pressure measurement in comparison:

Experimental setup and patient/sensor position during the study



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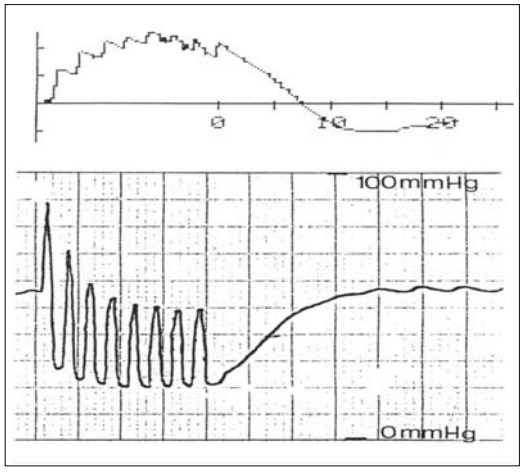
PPG and invasive vein pressure measurement in comparison:

Typical PPG (non-invasive) and VPM (invasive) records, measured simultaneously



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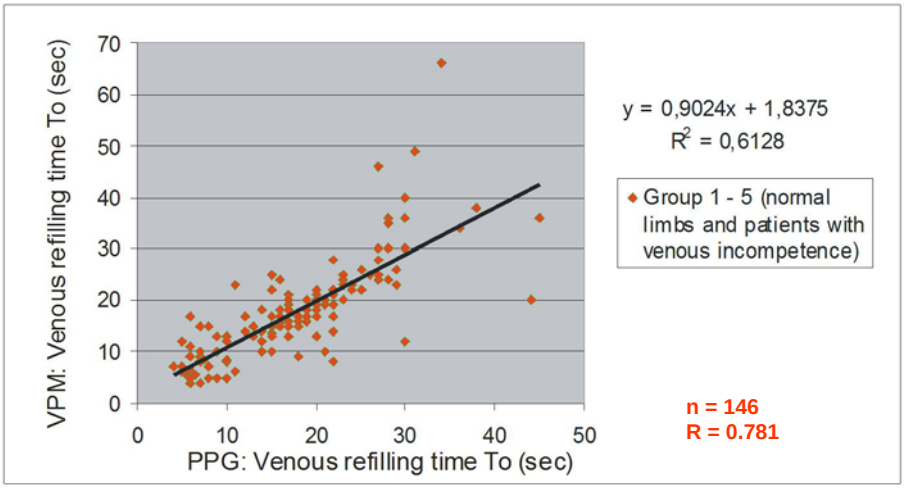
PPG and invasive vein pressure measurement in comparison:

Study results from 5 different research groups



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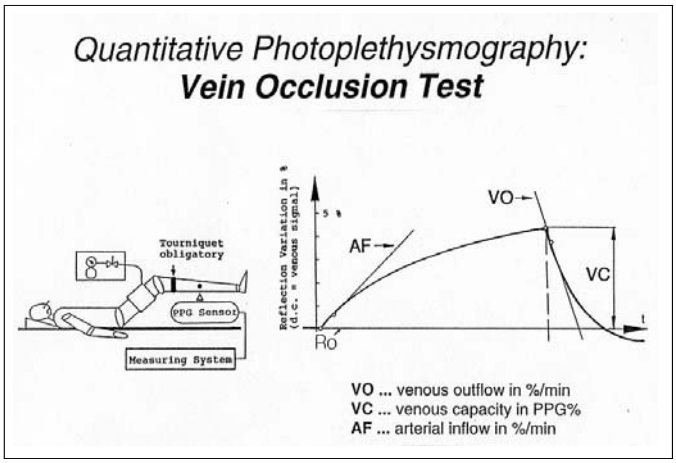
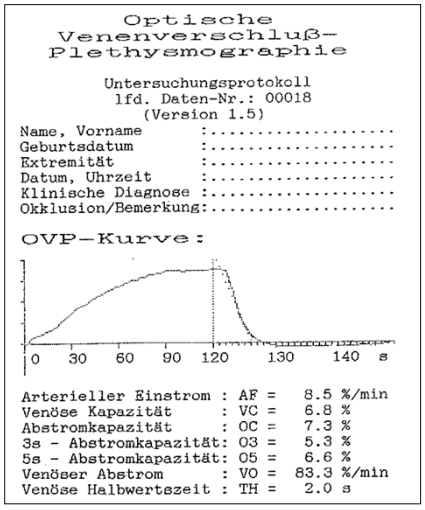
Second mostly used PPG test:

Venous occlusion test (VOT) for quantitative assessment of venous outflow dynamics



Second mostly used PPG test: VOT for the quantitative assessment of venous outflow



Optische
Venenverschluß-
Plethysmographie

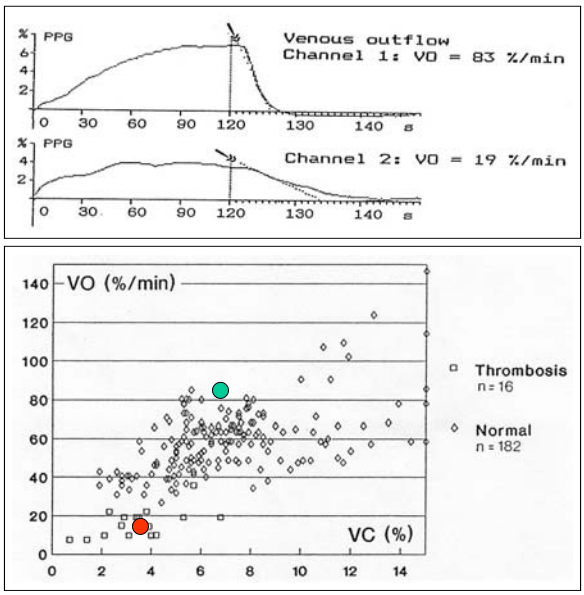
Untersuchungsprotokoll
lfd. Daten-Nr.: 00018
(Version 1.5)

Name, Vorname :.....
Geburtsdatum :.....
Extremität :.....
Datum, Uhrzeit :.....
Klinische Diagnose :.....
Okklusion/Bemerkung:.....

OVP-Kurve:

0 30 60 90 120 130 140 s

Arterieller Einstrom	: AF =	8.5	%/min
Venöse Kapazität	: VC =	6.8	%
Abstromkapazität	: OC =	7.3	%
3s - Abstromkapazität	: O3 =	5.3	%
5s - Abstromkapazität	: O5 =	6.6	%
Venöser Abstrom	: VO =	83.3	%/min
Venöse Halbwertszeit	: TH =	2.0	s



Normal outflow

DVT

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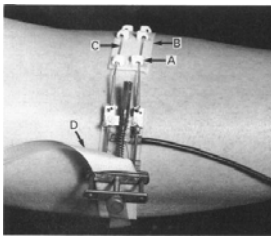
Alternative sensor concepts for blood volume studies in different compartments of human body:

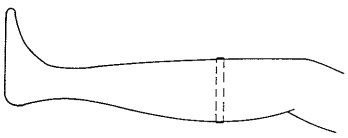
1) Strain gauge Plethysmography *

Um die untersuchte Extremität wird ein dünner, mit leitendem Fluid gefüllter und hoch dehnbarer Schlauch gelegt, dessen Längenveränderung als Änderung des elektrischen Widerstandes des Fluidmaterials registriert wird.

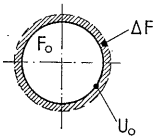
Umfangs – Querschnittsflächen - Relation



From: J. Physiol. 464 (1993), 407-422



Näherung



$$\frac{\Delta F}{F_o} = 2 \cdot \frac{\Delta U}{U_o} + \frac{\Delta U^2}{U_o^2}$$

Kriterium der geometrischen Ähnlichkeit muß bewahrt bleiben

Praxis

$$U = g \cdot \sqrt{F}$$

$$\frac{\Delta U}{U_o} = \frac{g \cdot \sqrt{\Delta F}}{g_o \cdot \sqrt{F_o}}$$

g..... Geometrie-faktor

* WHITNEY, R.J.: The measurement of changes in human limb volume by means of a mercury-in-rubber strain gauge. J. Physiol. 109, (1949), 5ff

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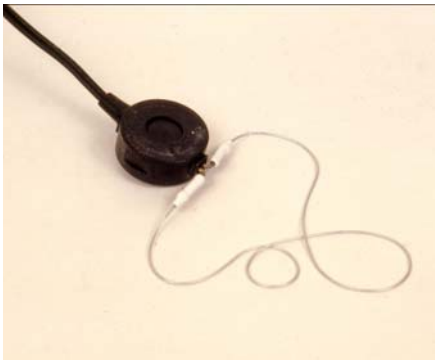
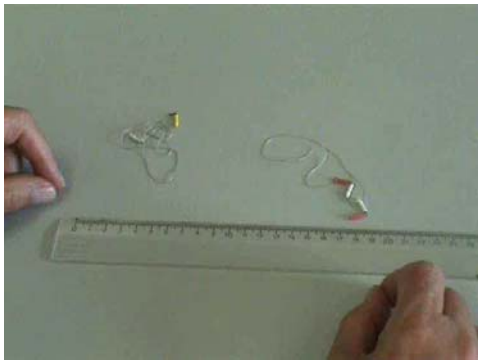
Alternative sensor concepts for blood volume studies in different compartments of human body:

1) Strain gauge Plethysmography *





Alternative sensor concepts for blood volume studies in different compartments of human body:

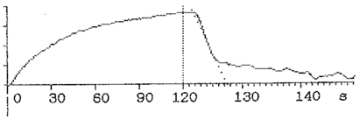
1) Strain gauge Plethysmography *

Digitale
Strain-gauge-
Plethysmographie

Untersuchungsprotokoll
lfd. Daten-Nr.: 00006
(Version 1.51)

Name, Vorname :.....
Geburtsdatum :.....
Extremität :.....
Datum, Uhrzeit :.....
Klinische Diagnose :.....
Okklusion/Bemerkung:.....

SGP-Kurve:



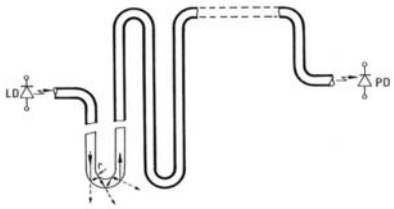
Arterieller Einstrom	: AF =	5.2 %/min
Venöse Kapazität	: VC =	3.6 %
Abstromkapazität	: OC =	3.3 %
3s - Abstromkapazität	: O3 =	2.2 %
5s - Abstromkapazität	: O5 =	2.4 %
Venöser Abstrom	: VO =	38.0 %/min
Venöse Halbwertszeit	: TH =	2.5 s

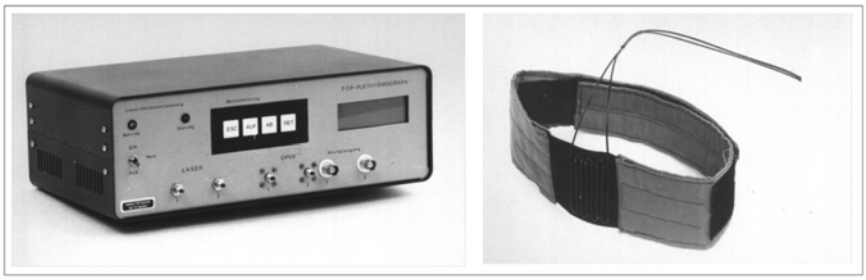
Alternative sensor concepts for blood volume studies in different compartments of human body:

2) Fiberoptic Plethysmography (RWTH Aachen)

Optical attenuation of FO banding sensor:

$$\alpha_{LWL} = f\left(r, \lambda, n_{Core}, n_{Coat}\right)$$





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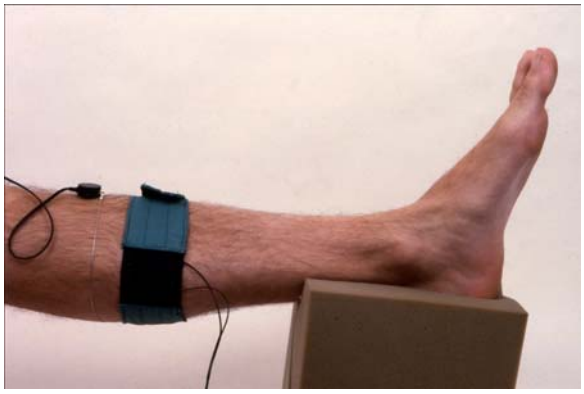
Alternative sensor concepts for blood volume studies in different compartments of human body:

2) Fiberoptic Plethysmography (RWTH Aachen)



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Alternative sensor concepts for blood volume studies in different compartments of human body:

3) Venous Impedance Plethysmography (RWTH Aachen)

Methodology: Two “injection” electrodes are connected to the AC source (20-70 kHz; ca. 1mA), two “sensing “ electrodes detect changes of tissue impedance as a function of total blood volume in the assessed extremity segment *

* After WHEELER et al., 1971

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Alternative sensor concepts for blood volume studies in different compartments of human body:

4) Air-Plethysmography (NICOLAIDES, IC London)
5) Water-Plethysmography (PARTSCH, Univ. of Vienna)

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Alternative sensor concepts for blood volume studies in different compartments of human body:

6) Gravimetric Plethysmography (RWTH Aachen)
7) Microwave Plethysmography (RWTH Aachen)

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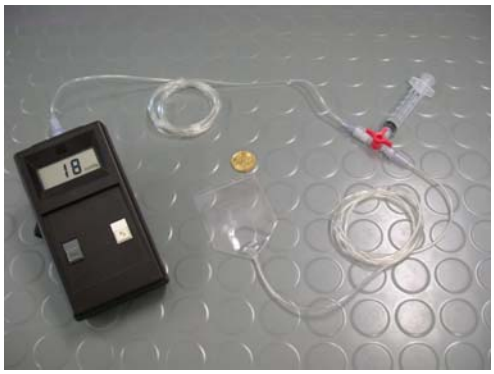
Alternative sensor concepts for blood volume studies in different compartments of human body:

8) Compression Interface Plethysmography (RWTH Aachen)
with a novel ***calibrated tandem sensor*** concept (Inflator with thin and flexible pneumatic sensor and piezo-electronic pressure converter), which avoids conceptional limitations of prevailing measuring systems.



Our prototype system data:

thin, flexible sensor
14x8x4 cm size 245 gram incl. 9V accu
analogue & digital data output
measuring range 0-100 mmHg
high time resolution
high sensitivity
low cost concept
PC/laptop compatible

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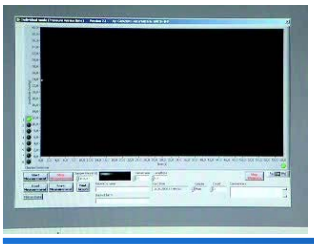
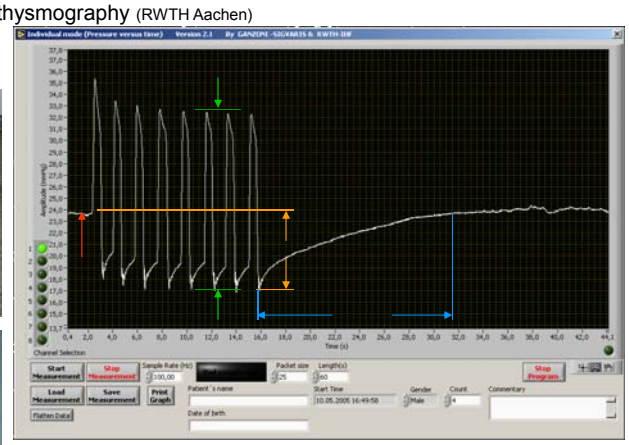
Alternative sensor concepts for blood volume studies in different compartments of human body:

8) Compression Interface Plethysmography (RWTH Aachen)

Typical results: Pressure behavior during standardized MP





Resting pressure: p_0 = 23.8 mmHg
Working pressure: p_A = 15.4 mmHg
Venous drainage: Δp = 6.8 mmHg
Venous refilling time: t_0 = 15.9 sec

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Citát pro sedmou přednášku / Quotation of the lecture 7:

“Study the past if you would diving the future”

CONFUCIUS (551 - 479 B.C.)
Chinese philosopher

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