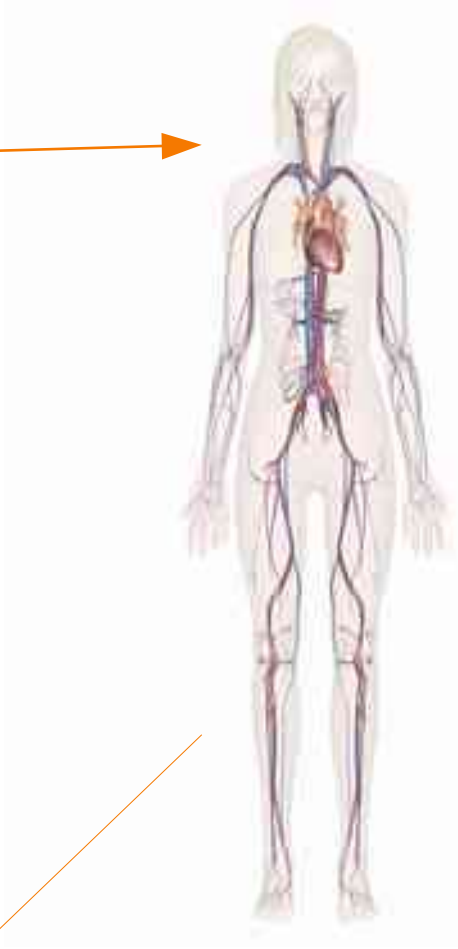
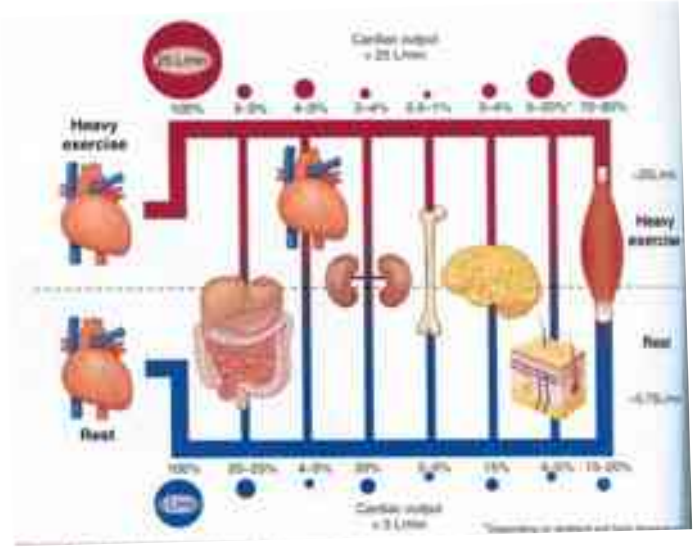
BLOOD VISCOSITY

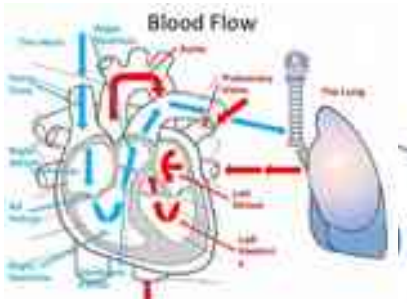
A concept of biology and mechanics

BIOLOGY



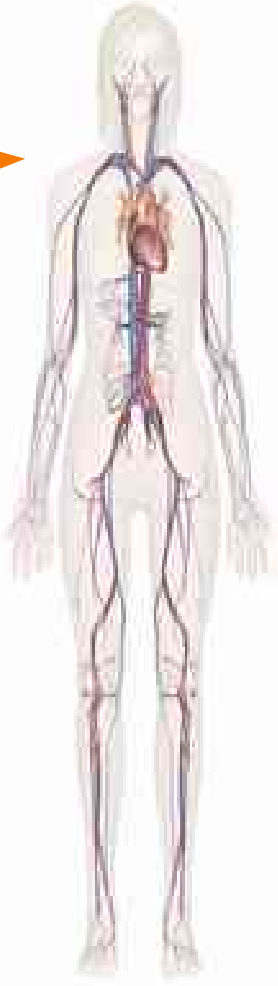


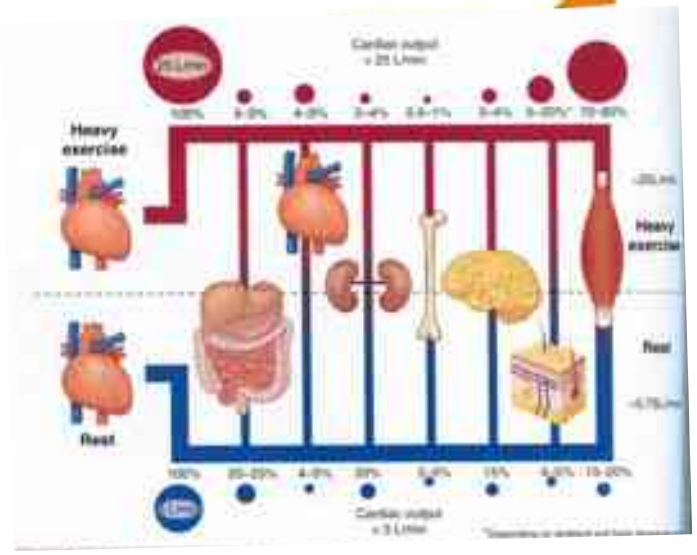
BIOLOGY

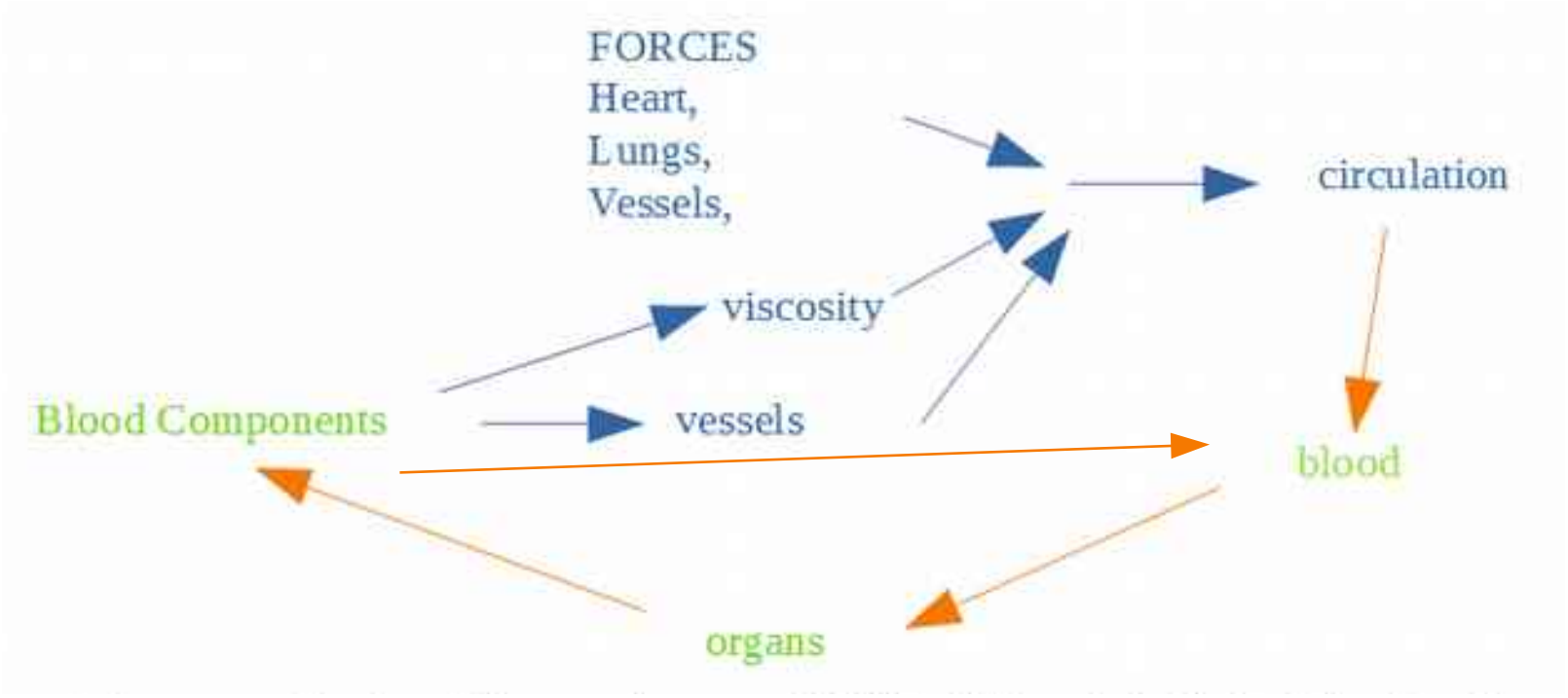


viscosité

MECHANICS







BLOOD VISCOSITY characterizes Hemodynamics frictions between

Fluids and Polyphasic elements of blood.

INTEREST is its Link between :

Biology and Physics in the organism : biomechanics

Potential : Measuring a significant factor

Ancient tests : **inflammatory state** of patients with **hyperviscosity**.
(diabete type II)

without knowing exactly when the accident but vulnerable to a CVD.

close to cholesterol case : when it is elevated, the patient is at risk while the accident is unpredictible.
It results dosing the cholesterol.

(source WOSCOPS **L'étude 4S**
(Scandinavian Simvastatin Survival Study) est une étude de prévention secondaire [13]. Lancet 1994 ; 344 : 1383-1389.).

THE MISSING THING IS RELATING
PATHOLOGIES
TO
BLOOD VISCOSITY

PLAN OF THE PRESENTATION

- State of art
- Cases pointing the effect of blood viscosity on health
- Blood viscosity : a factor on circulation and an indicator of blood composition

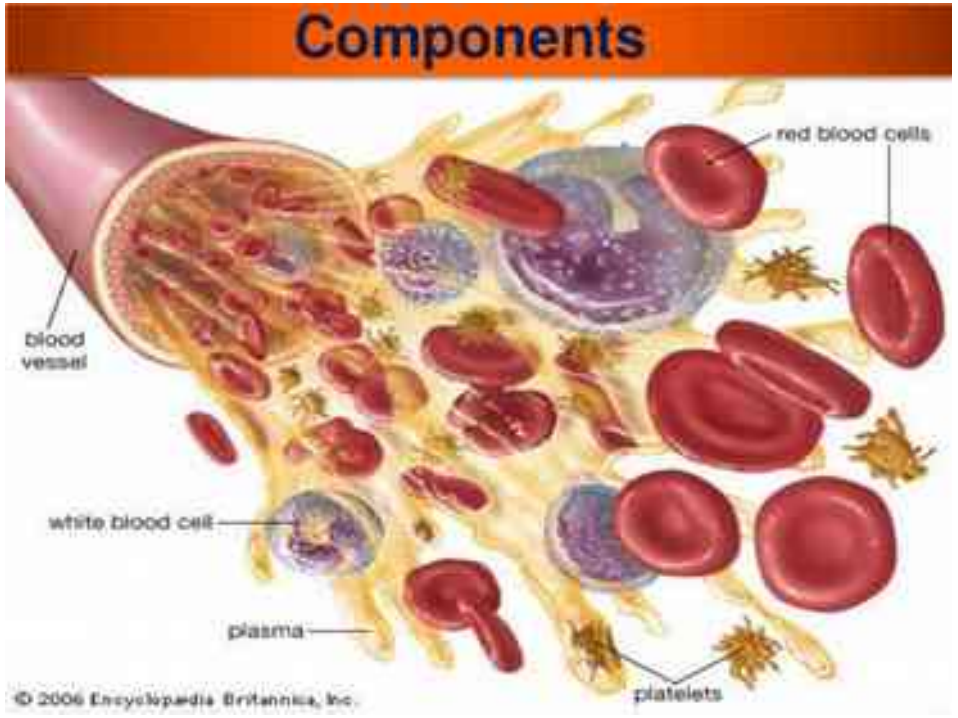
STATE OF ART

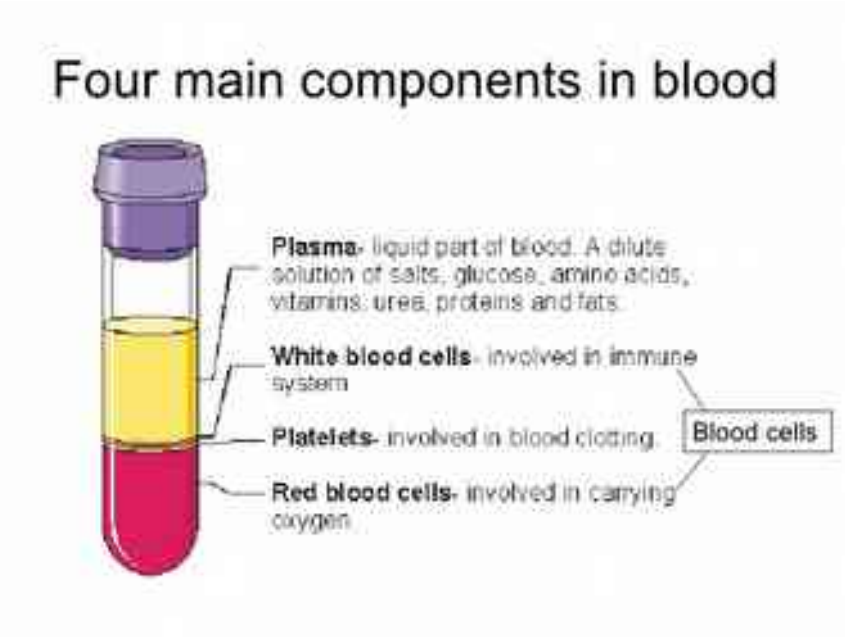
Blood viscosity is either measured by :

- blood flows (Couette, Poiseuille)
- indirect techniques

First, let’s clean the place

- Who said blood is a non Newtonian fluid ?

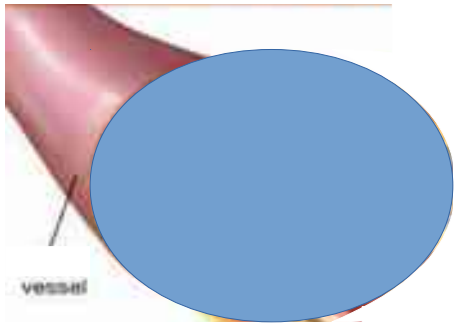


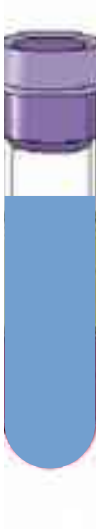


Blood separates, sedimentates

BUT a fluid, Newtonian or non Newtonian, NOT

- A fluid does not have components, it is purely atomic or molecular

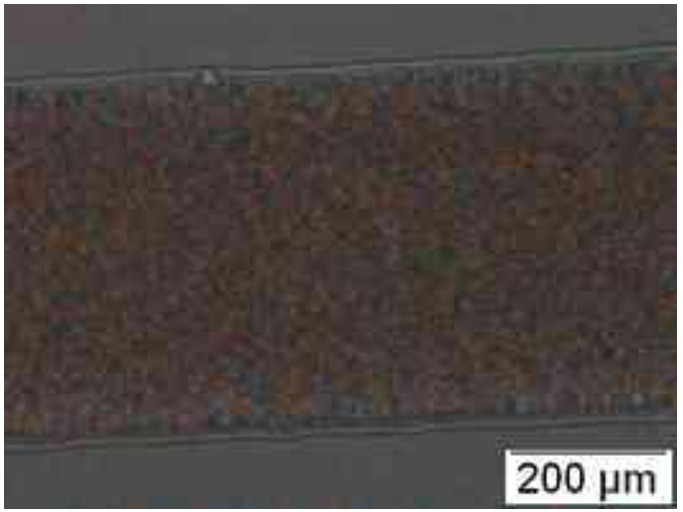


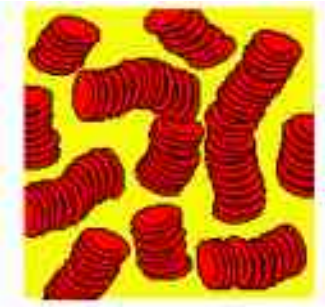


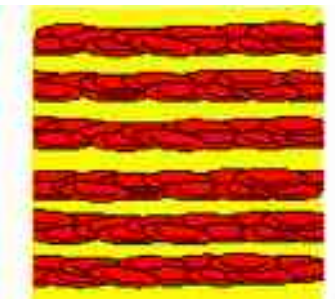
Continuous mechanics

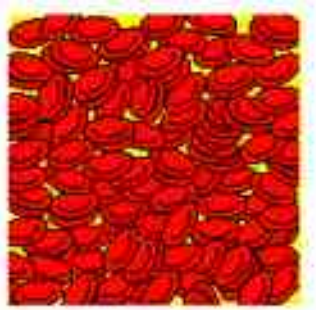
Viscosity depends on :

Blood components layouts in flow configurations...



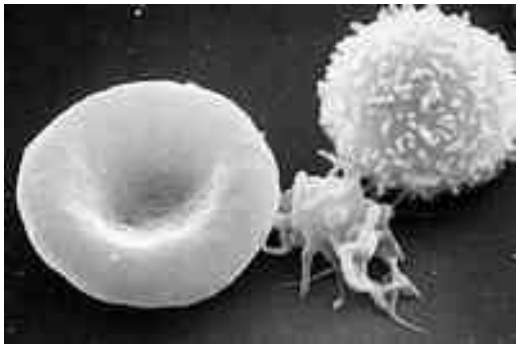






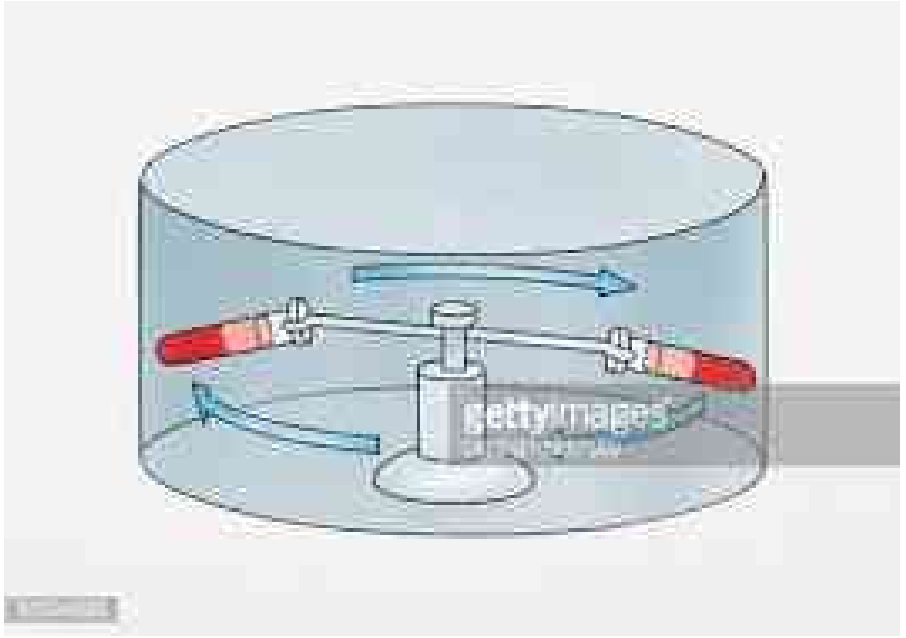
AND

Blood components : deformable solids, or, pure liquids.



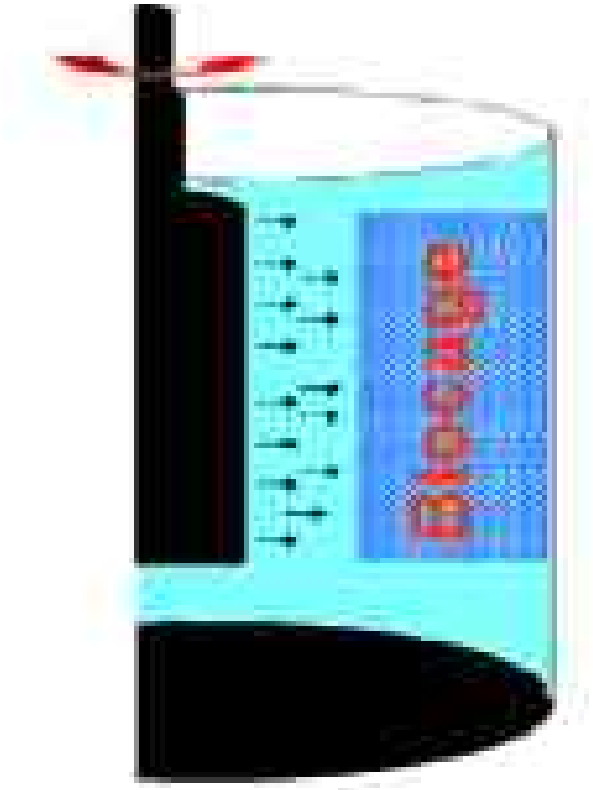
State of art

- DIFFERENT BLOOD FLOWS



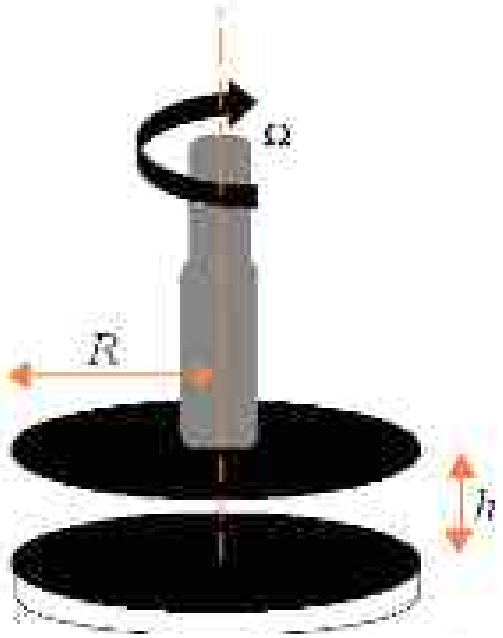
State of art

- Techniques of measure : cylindric Couette



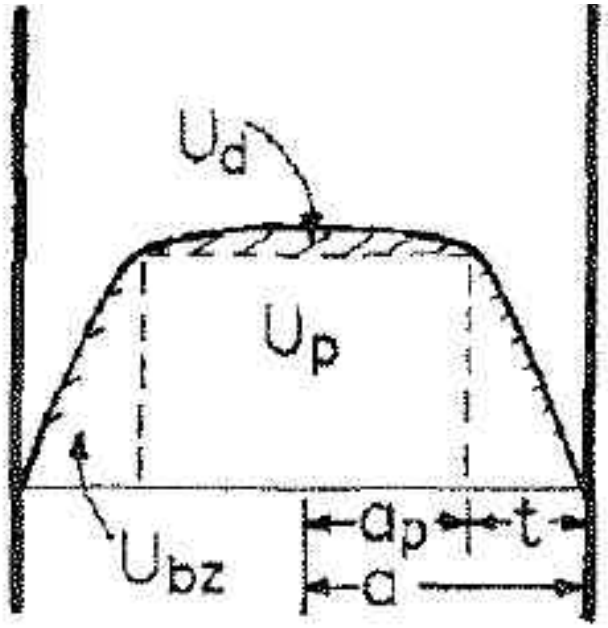
State of art

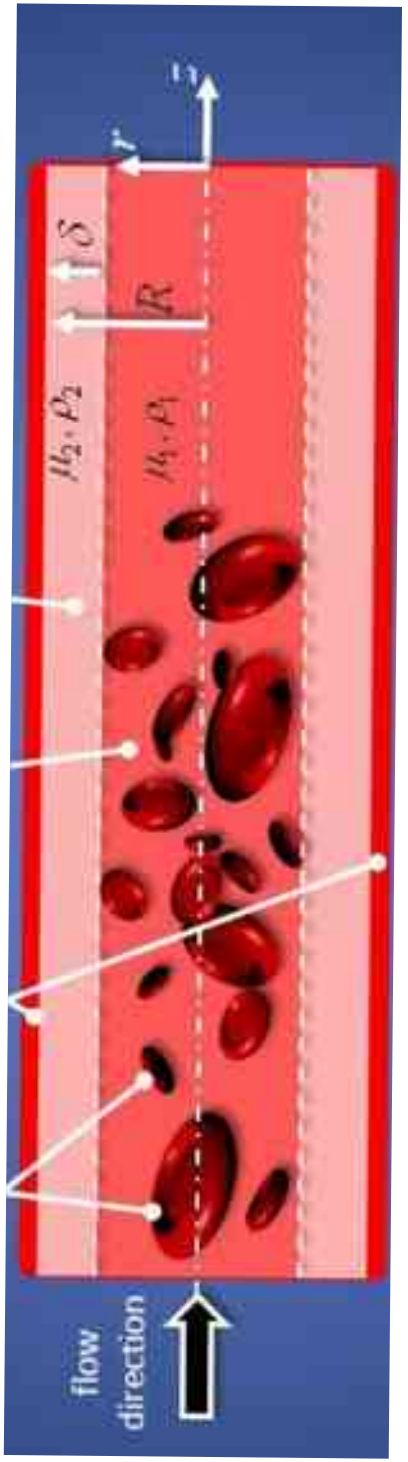
- Techniques of measure : plan – plan Couette



State of art

- 2 Techniques of measure : vessel Poiseuille fow





BLOOD

FLUID

		Newtonian	Non Newtonian
WRONG	Poiseuille's equation:	RIGHT	WRONG
	Blood flow = $8 \pi \Delta P r^4 \eta \lambda$		
WRONG	Newton's or Couette's equation:	RIGHT	RIGHT
	shear stress = η shear rate		

3 State of art - blood flow references

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November 2005 Minimization of Cell Migration between Flowing Blood and Concurrent Miscible Layers in a Microfluidic Environment

Christian P. Aucoin[1], Edgar E. Nanne[1], Edward F. Leonard[1], Nicholas G. Vitale[2], and Alan C. West[1]. (3) http://www.nature.com/articles/srep08840#ref27 Measurement of real pulsatile blood flow using X-ray PIV technique with CO_2 microbubbles, Hanwook Park, , Eunseop Yeom , Seung-Jun Seo , Jae-Hong Lim & Sang-Joon Lee, Scientific Reports 5, Article number: 8840 (2015)

(4) Journal of Visualized Experiments April 2013 | 74 | e50314 | Page 1 of 8 Micro-particle Image Velocimetry for Velocity Profile Measurements of Micro Blood Flows Katie L. Pitts Marianne Fenech

(5) Hybrid System for Ex Vivo Hemorheological and Hemodynamic Analysis: A Feasibility Study, Eunseop Yeom , Yang Jun Kang & Sang Joon Lee, Scientific Reports 5, Article number: 11064 (2015)

(6) http://www.researchgate.net/publication/

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(7) http://by.genie.uottawa.ca/~mfenech/PDF/ICNMM2012-73056.pdf ICNMM2012-730 56

Copyright © 2012 by ASME, BLOOD VELOCITY PROFILE MEASUREMENTS IN MICROCHANNELS USING MICRO-PARTICLE IMAGE VELOCIMETRY Katie L. Pitts, Marianne Fenech

(8) http://www.plosone.org/article/fetchObject.action?uri=info:doi/10.1371/journal.pone.0142945&representation=PDF

Citation: Lee SJ, Choi W, Seo E, Yeom E (2015)

Association of Early Atherosclerosis with Vascular Wall Shear Stress in Hypercholesterolemic Zebrafish. PLoS ONE 10(11): e0142945. doi:10.1371/journal.Pone.0142945 Editor: Alberto Aliseda, University of Washington, UNITED STATES

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Blood Flow and Cell-Free Layer in Microvessels DMITRY A. FEDOSOV*,†, BRUCE CASWELL‡, ALEKSANDER S. POPEL§, and GEORGE EM KARNIADAKIS* *Division of Applied Mathematics, Brown University, Providence, Rhode Island, USA †Institut für Festkörperforschung, Forsc

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State of art

- Indirect techniques of measure

  sedimentation speed,

  aggregation rate,

  coagulation,

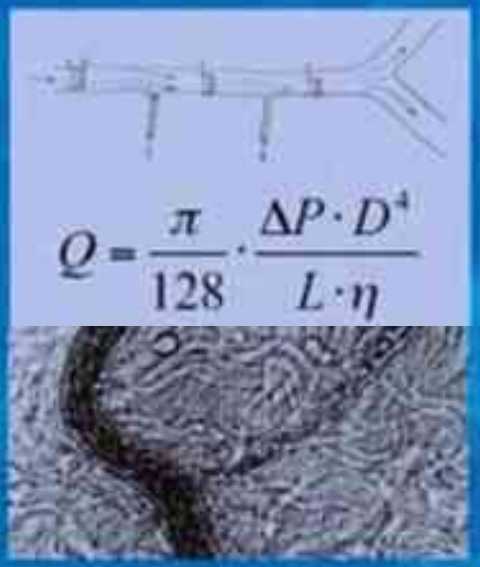
  Platelets,

  RBCs

These measurements are partially touching blood viscosity, see references...

Biomedical and Health Research

Hemorheology and Hemodynamics



Edited by
Oguz K. Baskurt, Max R. Hardeman,
Michael W. Rampling and Herbert J. Meiselman

State of art

Finally, in the 1980's, blood viscosity measurement was not supported
WHY ?

BECAUSE :

Methods : long, inaccurate, no reference values, calibration, nor case control

No **reference blood viscosity**

Diagrams of blood viscosity were almost unlimited, with histeresis, transition plateaux, etc.

No direct link between blood composition and viscosity

What is blood viscosity implication ?

All the techniques of measurement show the interest and the stake of blood viscosity

- Micro : friction between blood components
- Macro : constraints on CV net
- The linking factor between biology and mechanics

blood viscosity implication ?

– Comes from Micro scales

Internal forces of friction inside and between blood component :

WCs, Igs

RBCs,

Proteins

Cholesterol

Fibres, platelets

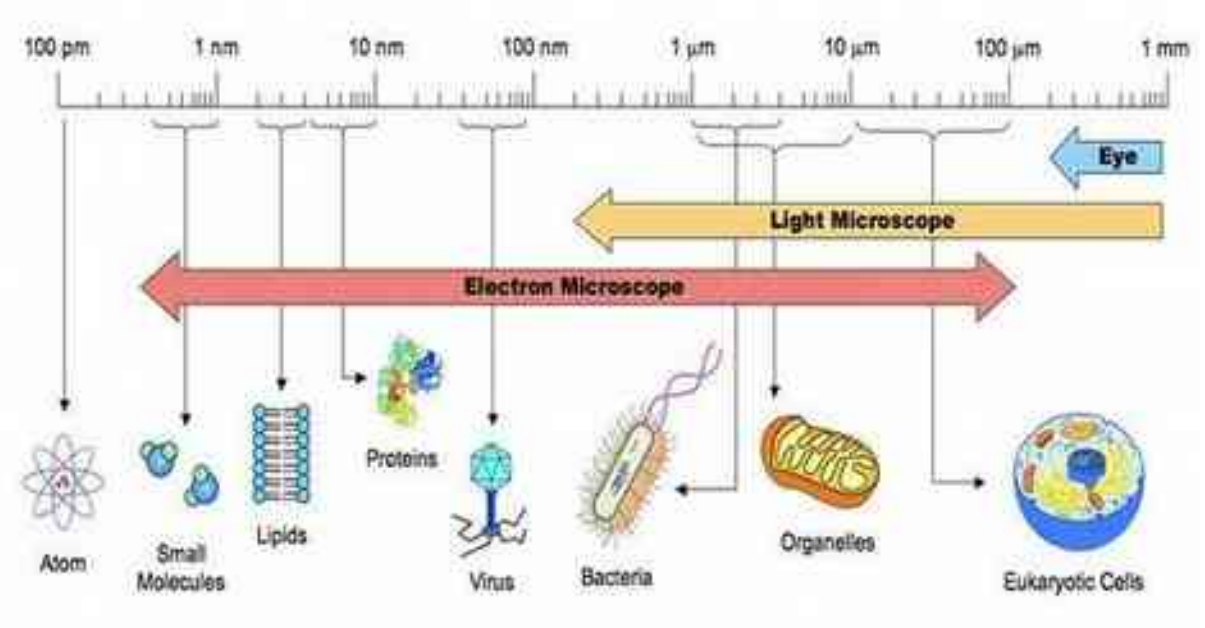
Von Willbrand factor, polymers

Waldenstrom macroglobulia

Hormones

Collagen

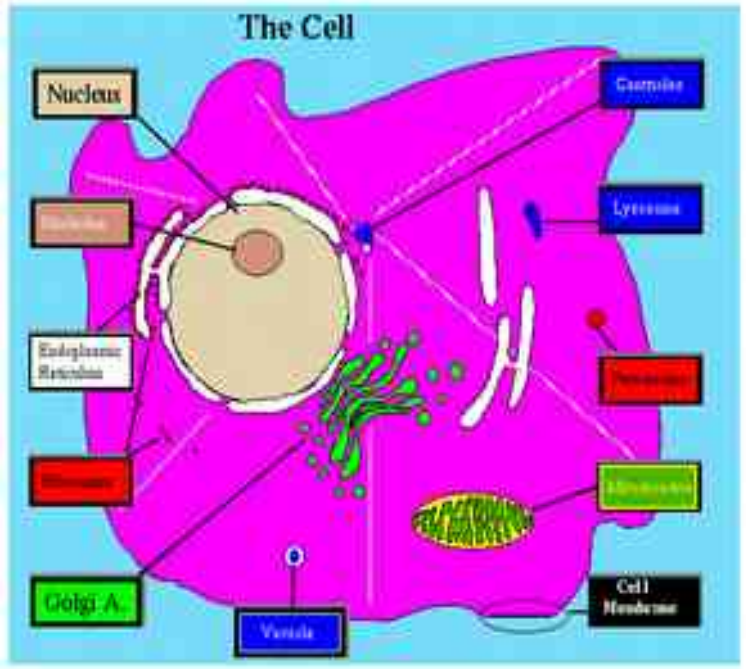
Plasma, serum

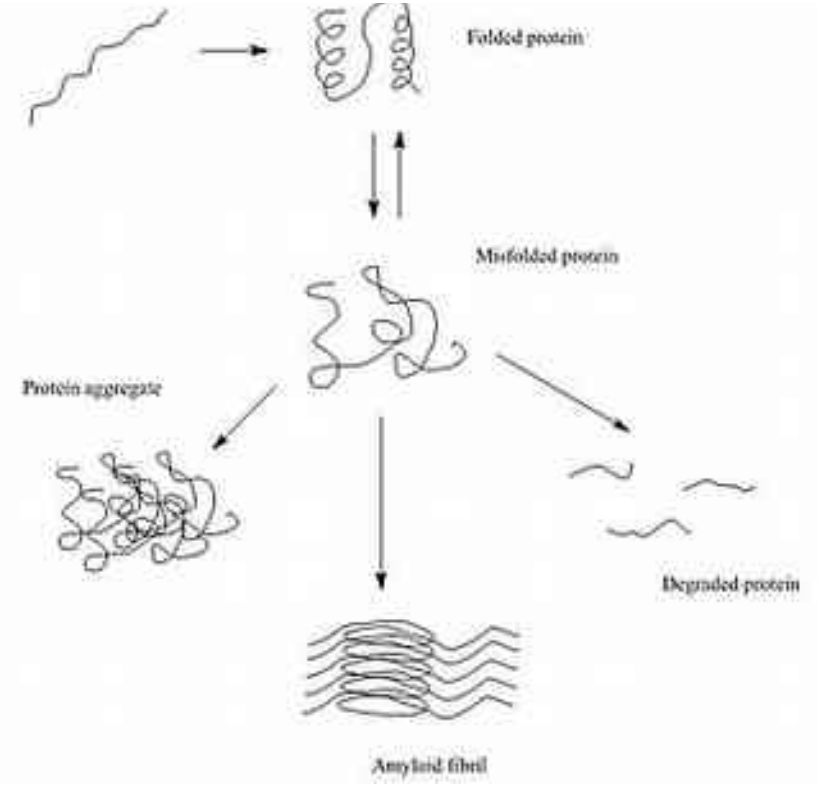


Hormones in bloodstream increase heart rate and blood pressure

blood viscosity implication ? MICRO

Blood viscosity is also a straining environment for cells, molecules



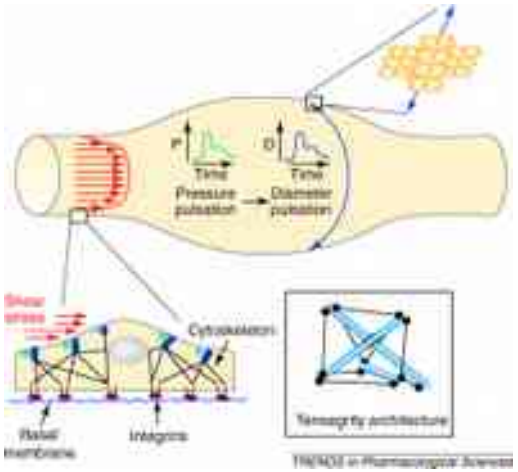


Blood viscosity implication ? MACRO

Endothelial shear stress is proportional to blood viscosity

Drag force :
longitudinal stretch

Pressure : radial axis opening



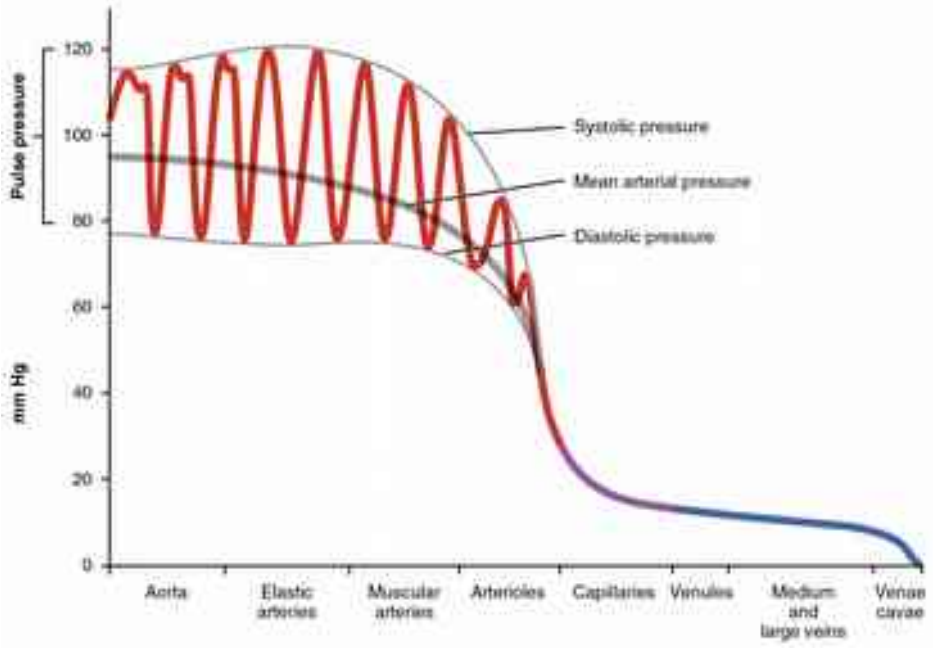
5 variables equally influence circulation :

- Cardiac output
- Compliance
- Volume of the blood (5 to 10L)
- **Viscosity of the blood**
- Blood vessel

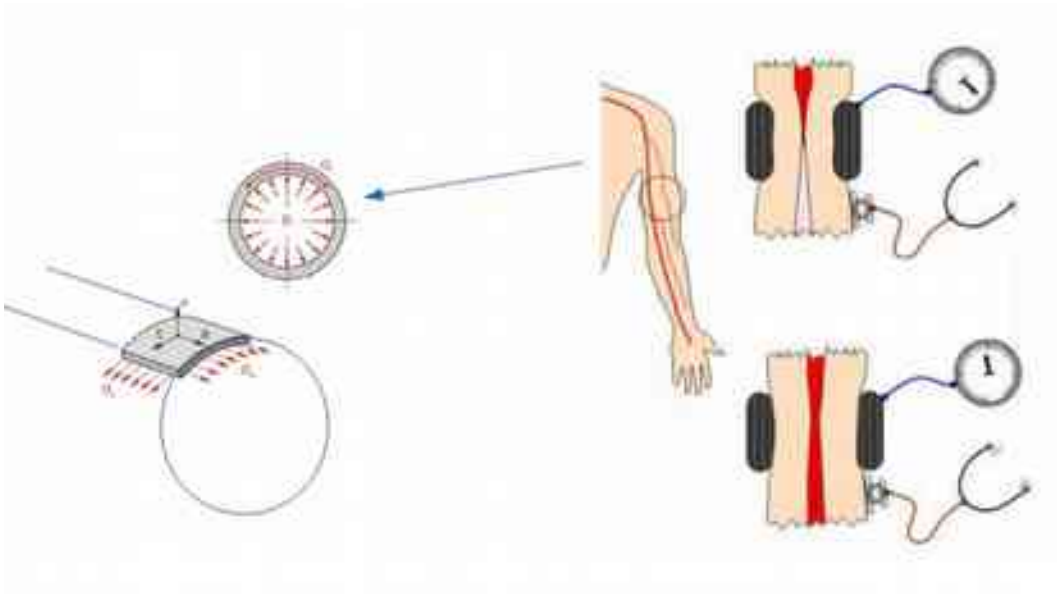
  length (100 000km)

  and

  diameter (µm to cm)



Value of pulse pressure in different type of blood vessels.

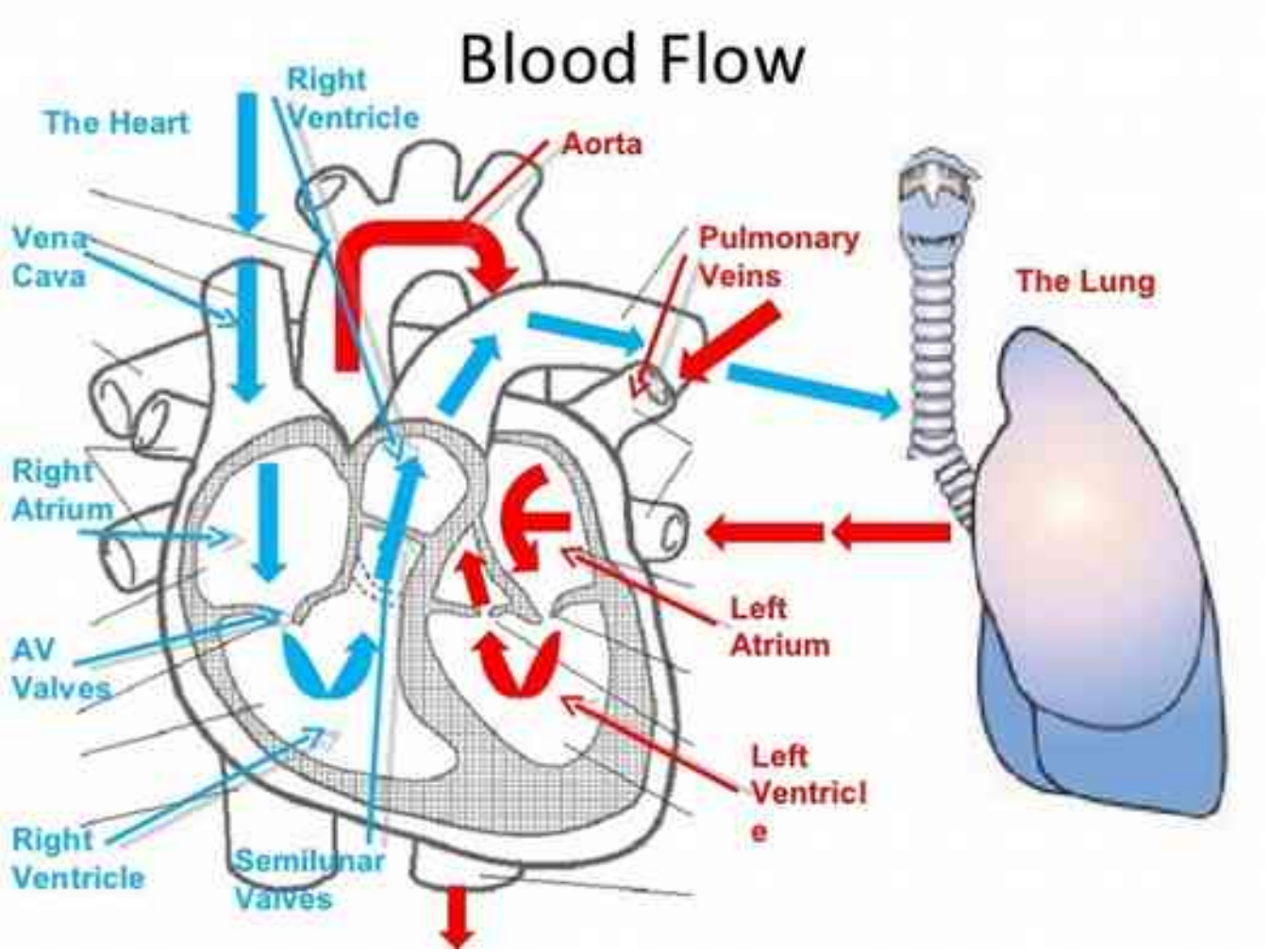


2 variables compensate **Viscosity of the blood** and can thus undergo fatigue or breack:

- Cardiac pressure (output : rate and energy)
- Blood vessels (dilatation, wall shear, NO)

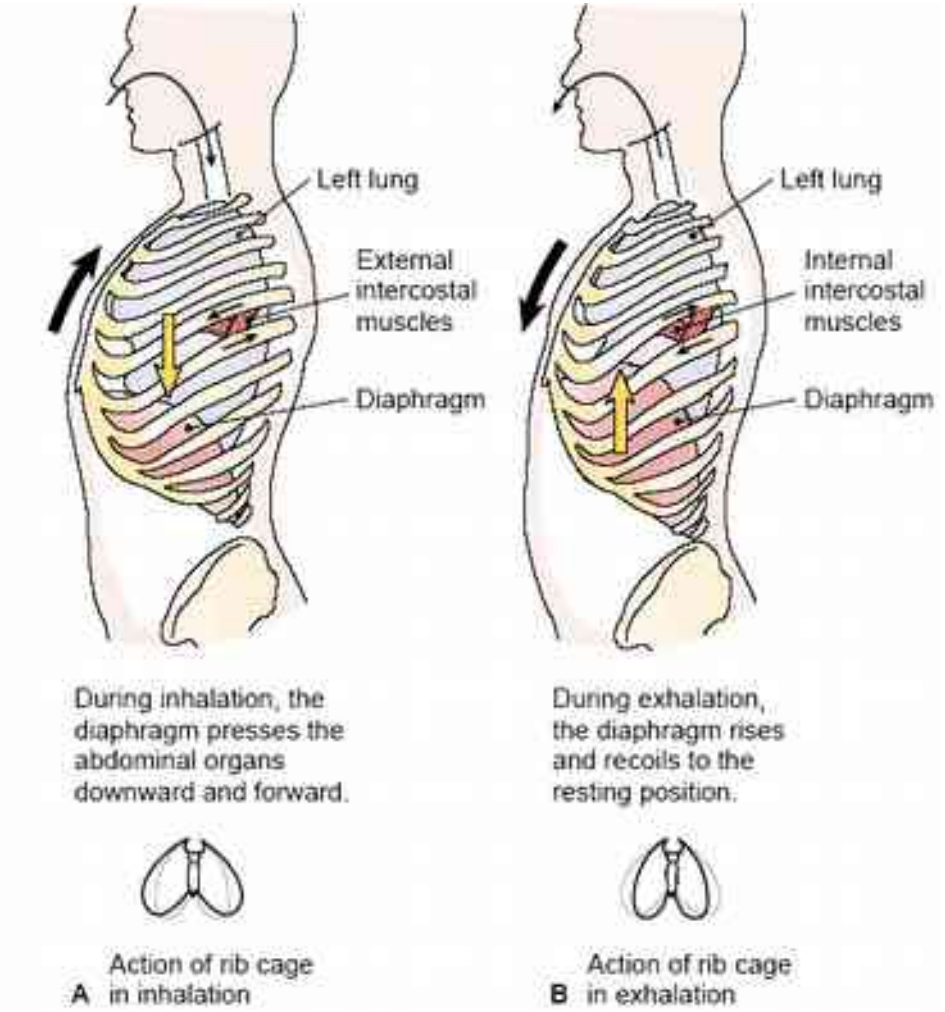
Blood viscosity implication ? MACRO

- **HEART** is a pump which mechanisms undergo blood viscosity



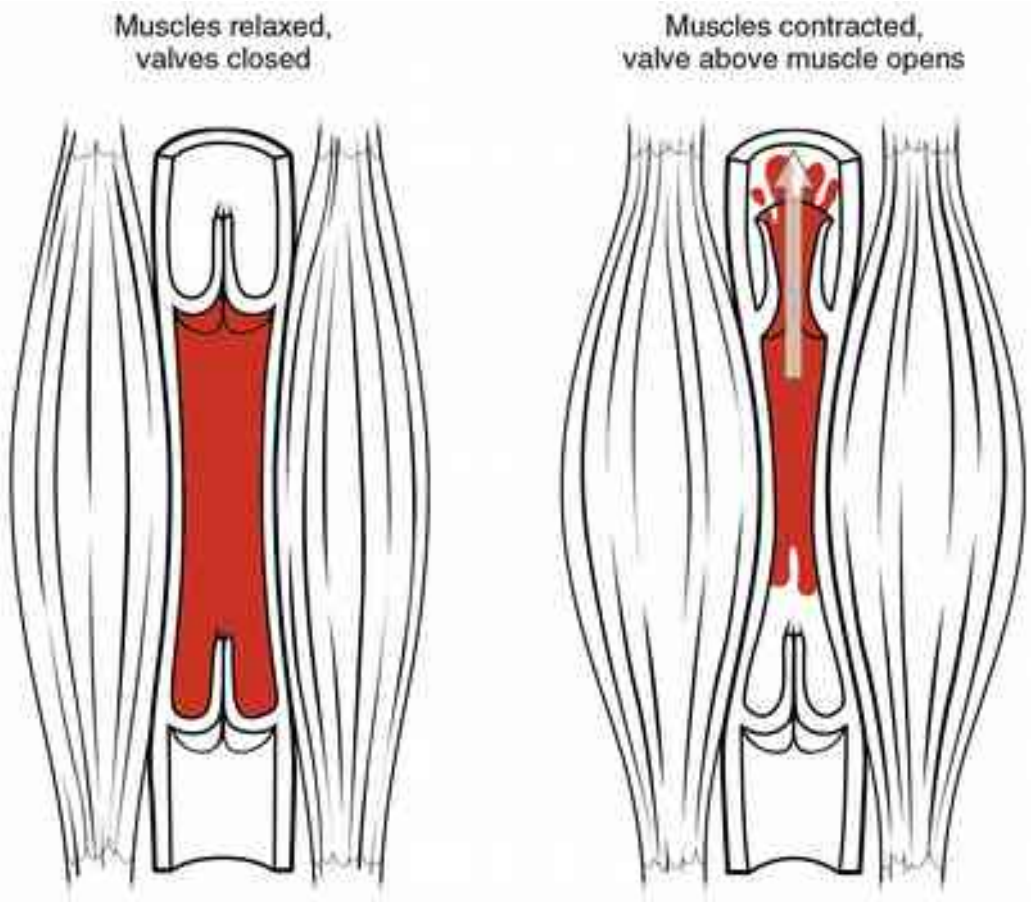
Blood viscosity implication ? MACRO

Lungs diaphragm work is confrontated to blood friction



Blood viscosity implication ? MACRO

- vessel activity Mechanisms compensate blood friction



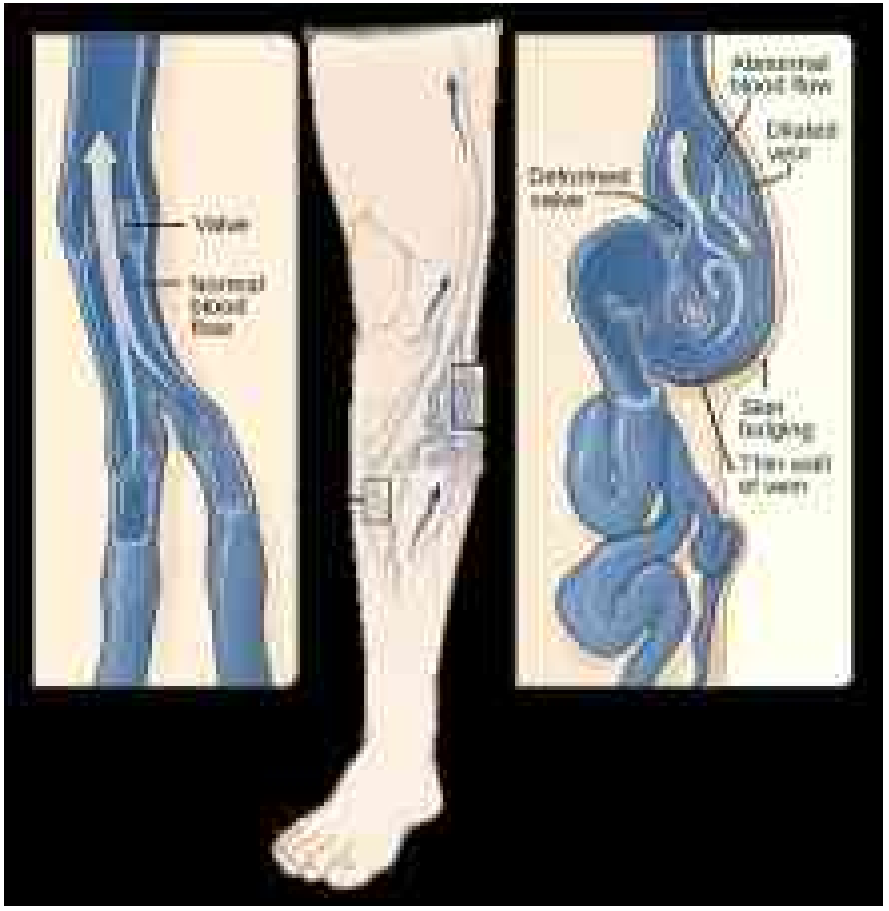
What is blood viscosity ? MACRO

Whatever the developments for making blood flowing, mechanical pieces of CV system are still strained :

- Endothelium
- Atherosclerosis
- thrombosis
- Valves
- Junctions

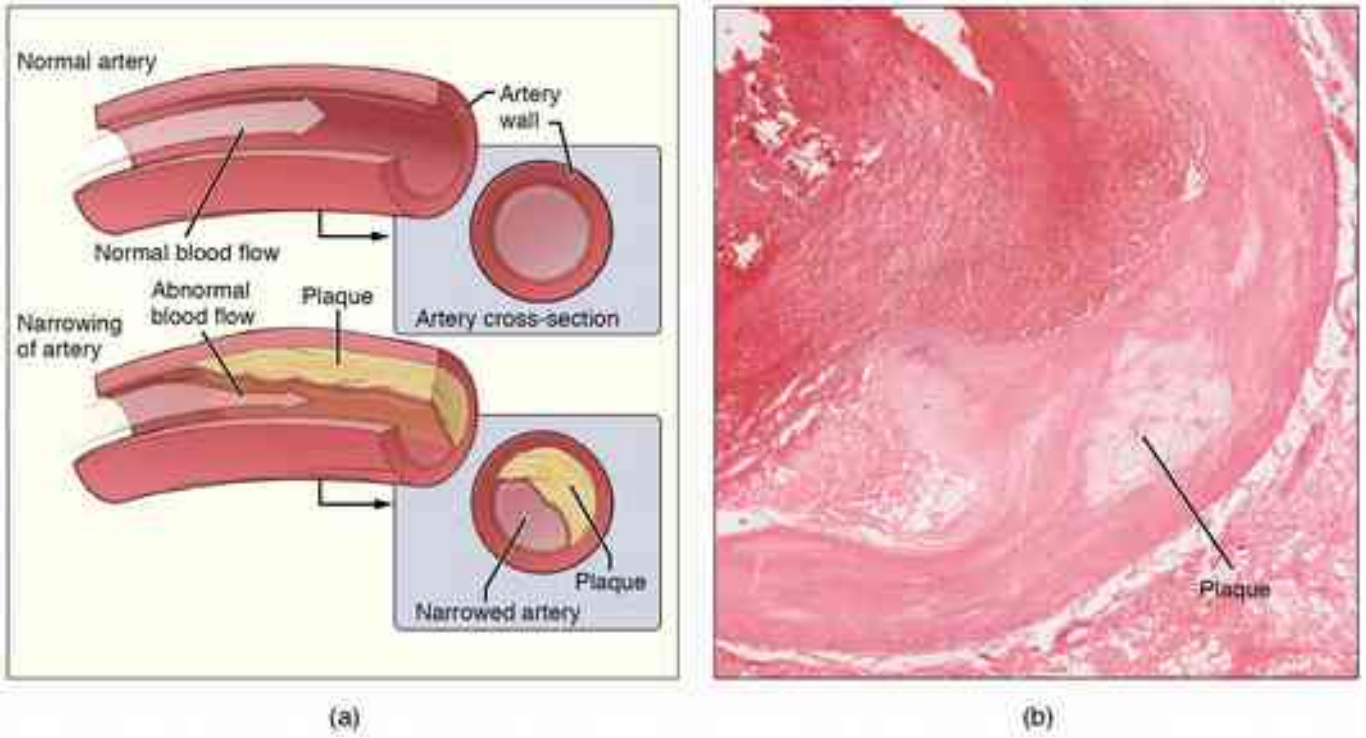
Blood viscosity implications ? MACRO

Consequences of too much vessel activities :



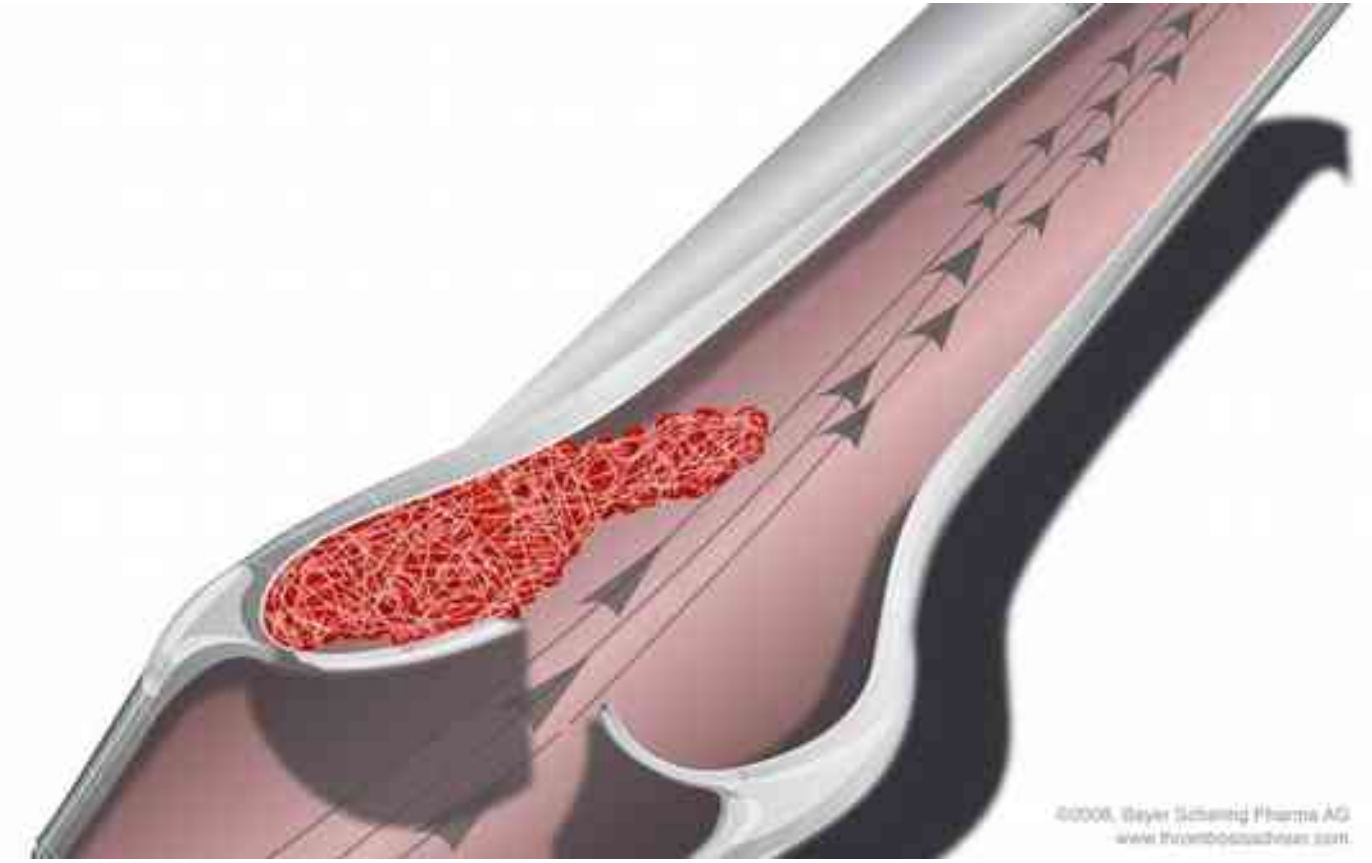
Blood viscosity implication ? MACRO

Atherosclerosis



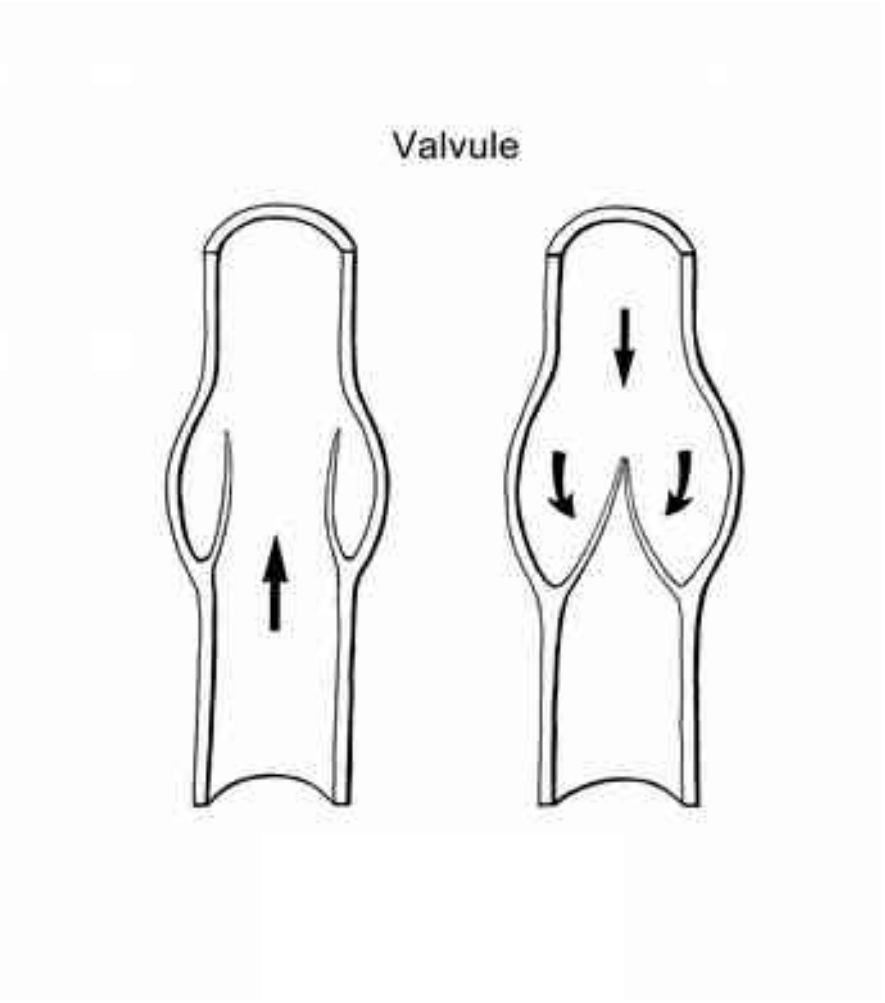
Blood viscosity implication ? MACRO

Thrombosis due to viscous recirculation and deposit



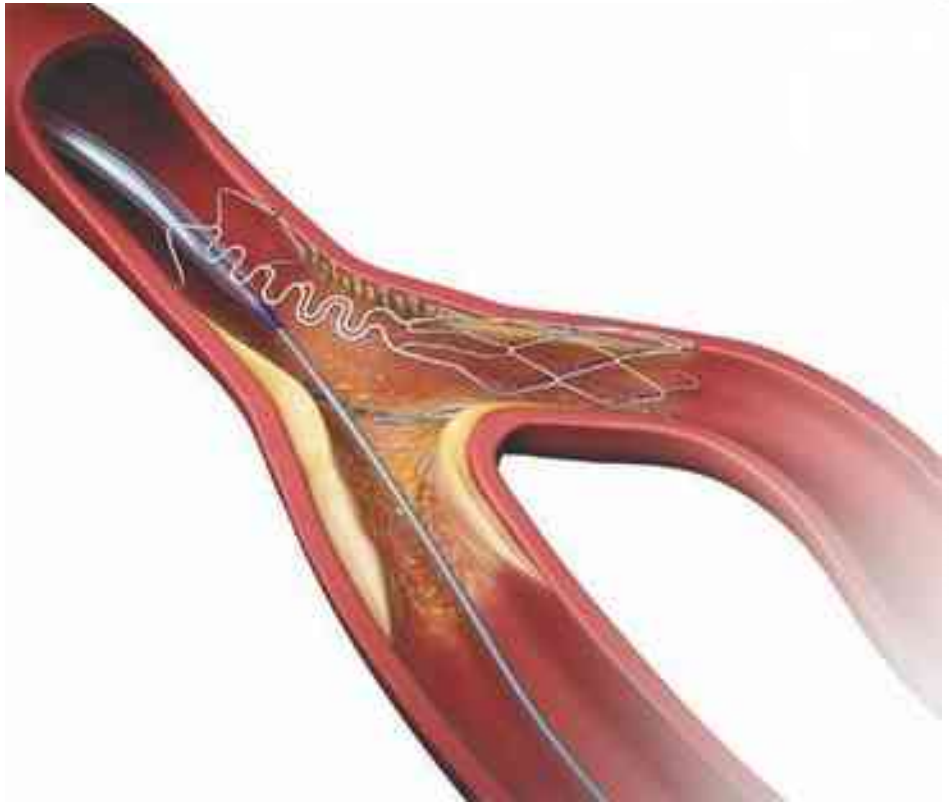
Blood viscosity implication ? MACRO

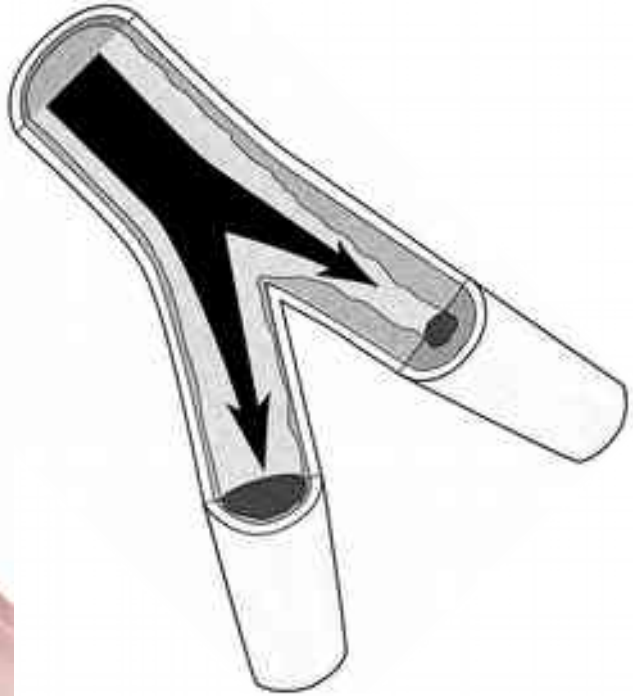
- Valvules support blood pressure → fatigue and break



Blood viscosity implication ? MACRO

Junctions, deposit, recirculation zone





Diseases in blood composition causing blood viscosity

inflammation

poliomyélites

polyglobulie

fibrines, von willbrandt facteur

leucémie

Maladie de Vaquez, Leucémie myéloïde chronique, Thrombocytémie essentielle

Blood viscosity is a factor in circulation affecting :

- Tension
- Pressure
- Blood rate
- Heart activity
- vessel activity
- Detachment of thrombus, atherom
- Strain on valves
- oxygenation

- SECONDARY EFFECTS : bad circulation (O2, CO2, Hormones)
  blood making coordination between organs

Diseases that could happen indirectly because of viscosity

Organs ischemia

CVDs

Troubles of equilibium and hear

infections in case of inflammation with the presence of an Ig in high quantity inhibates other Igs production, a high cause of mortality

Kidneys pressure

Bad circulation of necessary biological components : hormons, labile comoponents

- Publications showing the importance of blood viscosity in general health

1 Fahey, J. L., Barth, W. F., and Solomon, A.,
Journal of the American Medical Association, 1965, 192, 464.
2 Somer, T., Acta Medica Scandinavica, 1966, 180, Suppl. No. 456.
3 Shearn, M. A., Epstein, W. V., and Engleman, E. P., Archives of Inteirnal Medicine, 1963, 112, 68
4 Jasin, H. E., Lospalluto, J., and Ziff, M., Amer-ican 7ournal of Medicine, 1970, 49, 484.
5Kopp, W. L., Beirne, G. J., and Burns, R. O., American 7ournal of Medicine, 1967, 43, 141.
6 Smith, E., Kochwa, S., and Wasserman, L. R., American lournal of Medicine, 1965, 39, 35.
7 Br J Haematol. 1997 Jan;96(1):168-73.
Blood viscosity and risk of cardiovascular events: the Edinburgh Artery Study.
Lowe GD1, Lee AJ, Rumley A, Price JF, Fowkes FG.
8 G. DumasLa revue de m?®decine interne, Corrected proof. doi:10.1016/j.revmed.2015.02.005
Dumas G, et al. Syndrome d'hyperviscosité plasmatique. Rev Med Interne (2015), http://dx.doi.org/10.1016/j.revmed.2015.02.005

Conclusion on blood viscosity

- VISCOSITY :
  - Comes from inner friction between blood components
  - Depends on blood components shapes
    - Atoms liquid, solid, gas
    - Proteins, macromolecules
    - Cells
- VISCOSITY amplifies :
  - Drag force, pressure, flow rate
  - Vessel wall strain
  - Deformation of blood component

- BUT There is no available device, neither common method

4

NEW BLOOD VISCOSITY MODEL

NEW MODEL Ambition

Reactivate blood viscosity interest and measurement

++ orientate CVDs diagnostics
+++ indicator of blood composition only

MORE DIRECTLY and SIMPLY

- history of blood viscosity measurement :

It all started using
Newton (1642-1727), and Einstein (1879-1955) principles on viscosity of continuous fluids under Brownian motion (1773-1858)

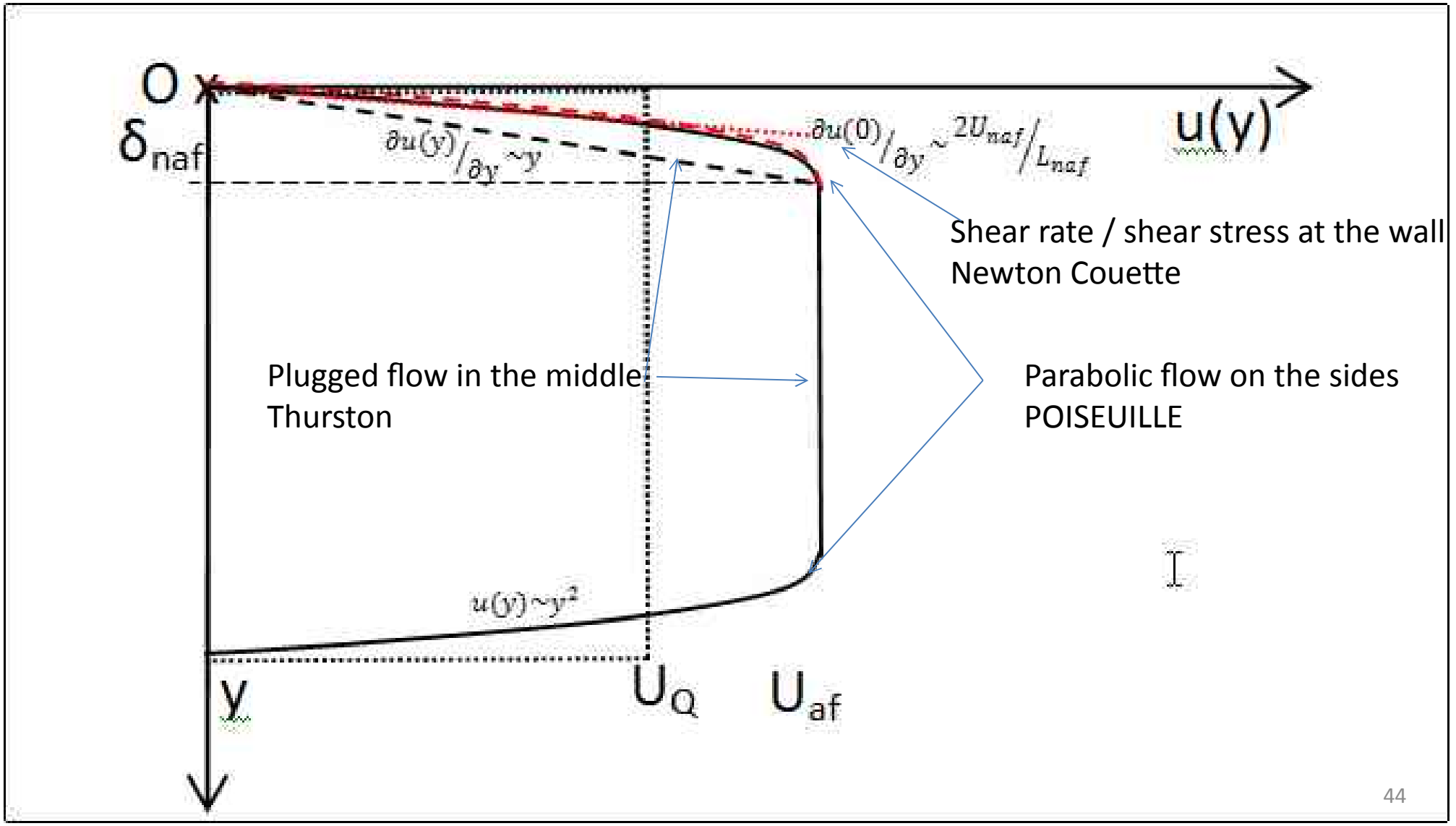
Poiseuille (1797-1869) in a vessel but the law is only working for fluids
Couette (1858-1933) in a rotating cell but the rotating make RBCs migrate
Thurston (1980's) in vessel taking into account sheath flow but with a linear layer
Tilly (2016) in a vessel taking into account sheath and plug flow with a parabolic layer

- New model of blood viscosity measurement :

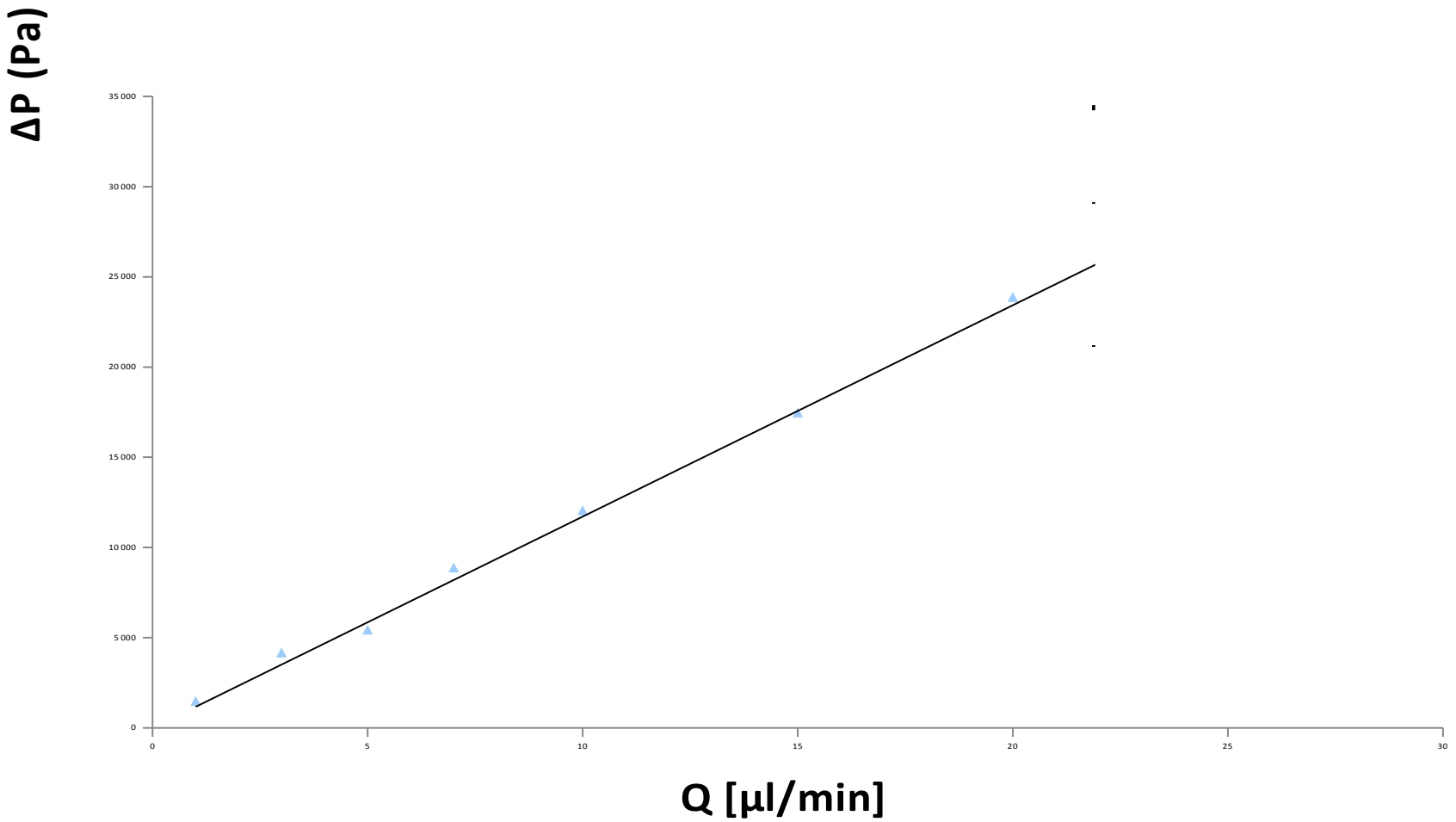
Integration of 3 former models

Schematics principle of blood flow in a vessel

In the wall layer, δ_{naf}, the flow is not plugged and follows experimentally a Parabolic profile (PIV)



Pressure drop coefficient K is constant, and the geometrical factor G fits for the water case (viscosity constant).



- This gives the three different values of I_{fs} measured for these three fluids, easy to compare and to appreciate for fluidity estimation

- Constant Index is viscosity * D / Lnaf
  - Viscosity of blood
  - D size of channel
  - Lnaf size of attached flow

Measures, controls :

- dP
- L
- Q
- Dh
- Lnaf

At any shear, a unique viscosity index explaining :
the friction at the wall, the dissipation in the flow, the ability of blood to flow

Originality of the new model

Easier, simple, to use because no problem of how put the blood in the device

Quick (30s)

Minimal volume : 1mL

Reproducibility

Unique measure for a unique composition of blood

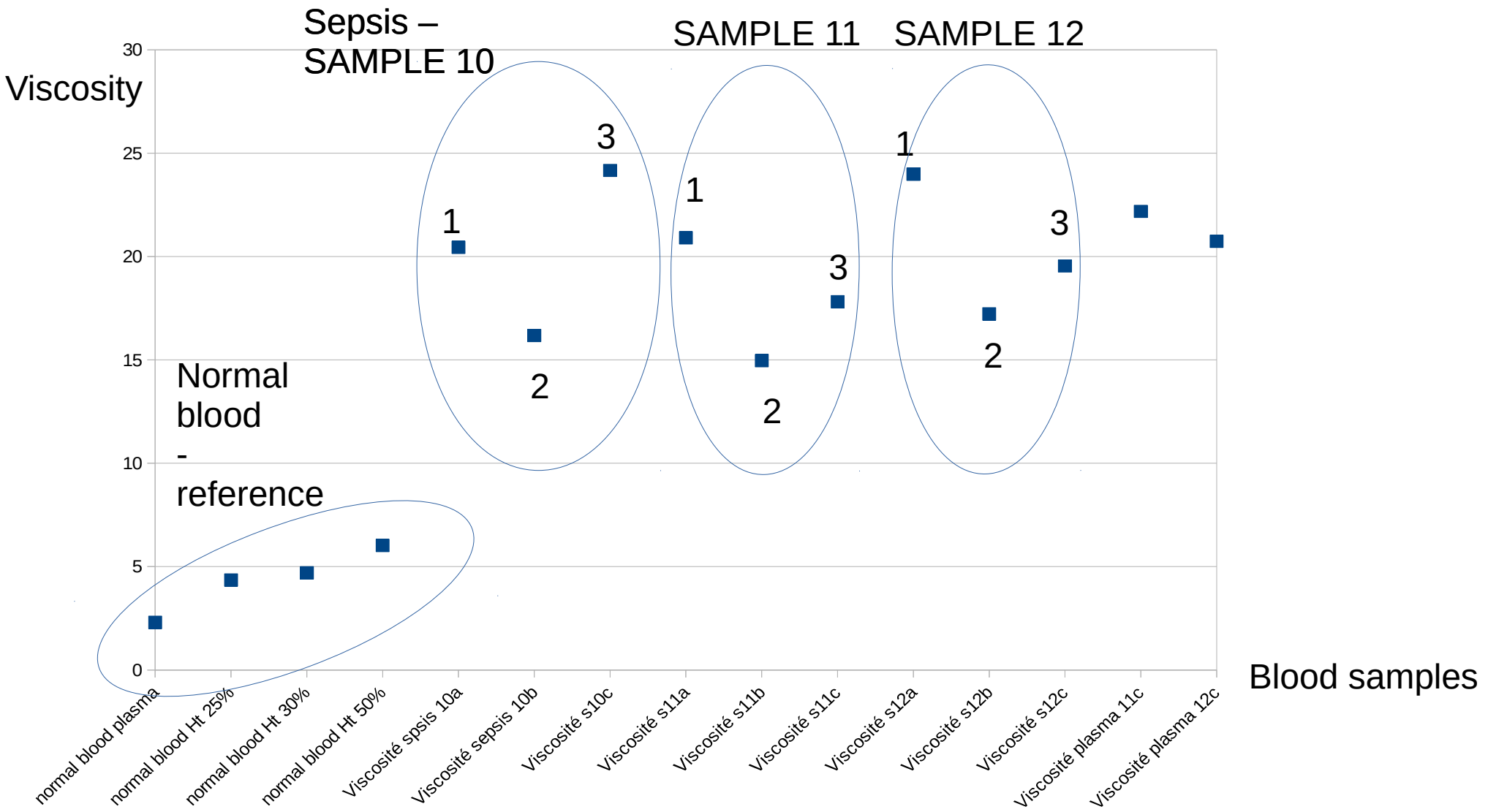
Precision

Reference case

- Algorithm : Measurement of force and flow rate in established permanent flow
- Protocole : take a blood sample (1mL)
- Device : capillary with sensors
- Data : blood viscosity, blood formulation

5 DATA RESULTS

- NORMAL BLOOD
-
- PLASMA
-
- Influence of RBCs
-
- Sepsis case


Sepsis – SAMPLE 10
SAMPLE 11
SAMPLE 12
Viscosity
Normal blood - reference
Blood samples
30
25
20
15
10
5
0
1
2
3
1
2
3
1
2
3
normal blood plasma
normal blood Ht 25%
normal blood Ht 30%
normal blood Ht 50%
Viscosité spsis 10a
Viscosité sepsis 10b
Viscosité s10c
Viscosité s11a
Viscosité s11b
Viscosité s11c
Viscosité s12a
Viscosité s12b
Viscosité s12c
Viscosité plasma 11c
Viscosité plasma 12c

Results interpretation

- Sepsis is 10 times more viscous than normal blood

- Plasma viscosity is lower than total blood in normal case

  BUT higher than total blood in

  sepsis case

- We understand here that Hc is not the most important parameter that influences blood visosity ans thus a hydraulic resuscitation is not of good effect systematically, might be the opposite

- Sepsis is correlated to hyperviscosity

6 Interest at measuring viscosity evolution

- Perspectives : measuring viscosity is an interesting indicator of blood composition
- Blood viscosity is a revelator of inflammation monitoring

- As RBCs are not systematically increasing blood viscosity, a reconstruction of blood viscosity data is necessary

Conclusion

- Blood viscosity is a simple variable in the middle of complex health factors. It is :
  - Before all. A resulting mechanical property of blood composition organization in blood stream
  - At first order. A mechanical symptom of blood circulation
  - At second order. A key factor of blood flow : friction, pressure, ability to flow
  - At third order. An index of CVDs, hemogram
  - Implicitly. Plays on vessels activities, blood metabolism
- Blood viscosity is unique
- Blood viscosity is quick and easy to measure in a blood analysis.

Perspectives

- Correlate blood viscosity to blood composition and CVDs
- Find cases where blood viscosity is a unique role in a particular known disease
- Make a simple device for routine measures