PHYSIOLOGY OF BLOOD

FUNCTIONS OF BLOOD

HOMEOSTATIC FUNCTION

buffering

thermoregulation (transport of heat)

TRANSPORT OF SUBSTANCES

(blood gases, nutrients, metabolites, vitamins, electrolytes…)

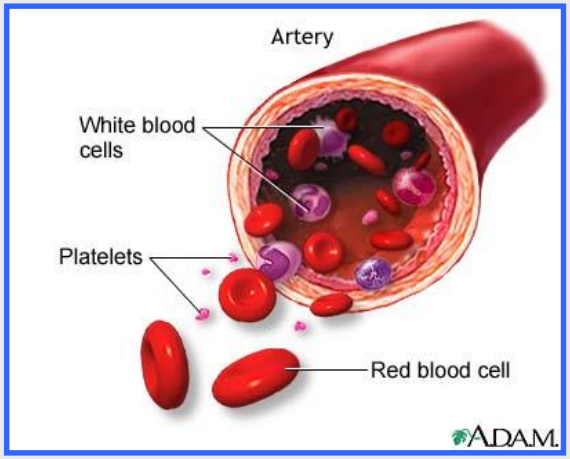
HUMORAL CONTROL OF ORGANISM (hormones)

DEFENCE OF ORGANISM (immune functions)

BLOOD CLOTTING

BASIC CHARACTERISTICS

- **Suspension** character
- 6 - 8% total body mass
- 55% - **fluid** phase (plasma)
- 45% - **formed** phase (blood cells and platelets)
- **Serum**: from plasma during blood clotting – after consumption of fibrinogen



BONE MARROW

Size (1600-3000 grams), activity.

Red bone marrow, **yellow** bone marrow.

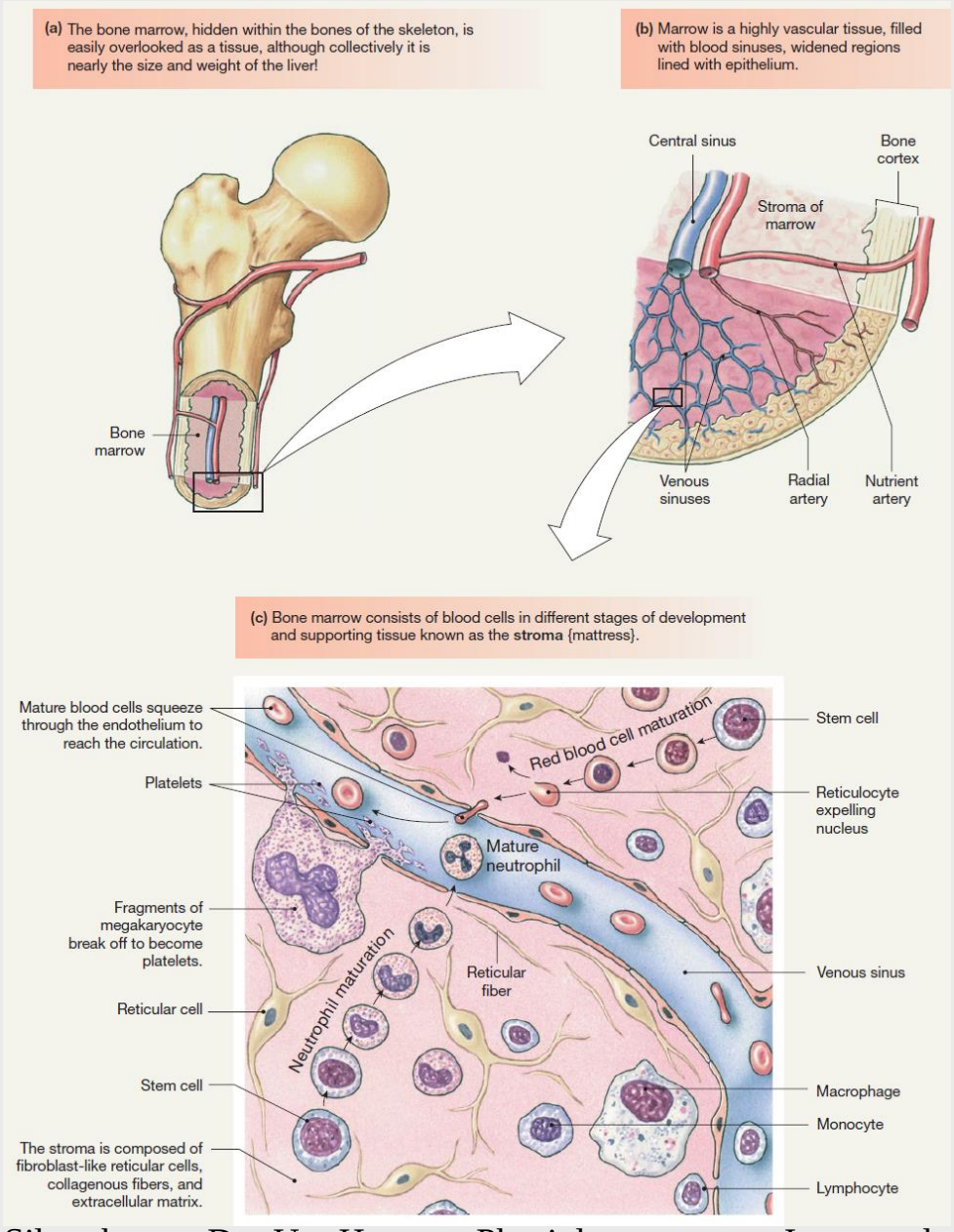
Pluripotent stem cells.

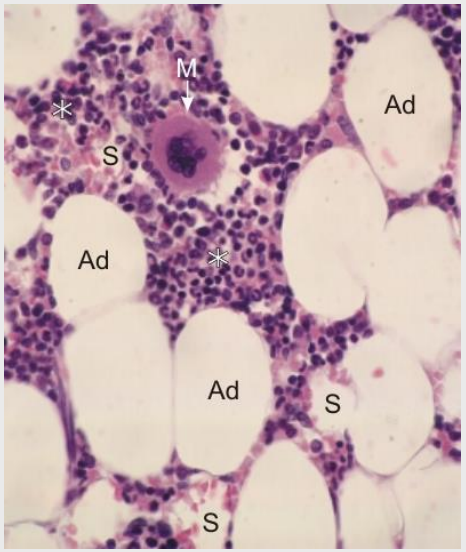
Unipotent (determined) stem cells – differentiated cells.

Extra-medullar haematopoiesis – liver, lien – CHILDREN.

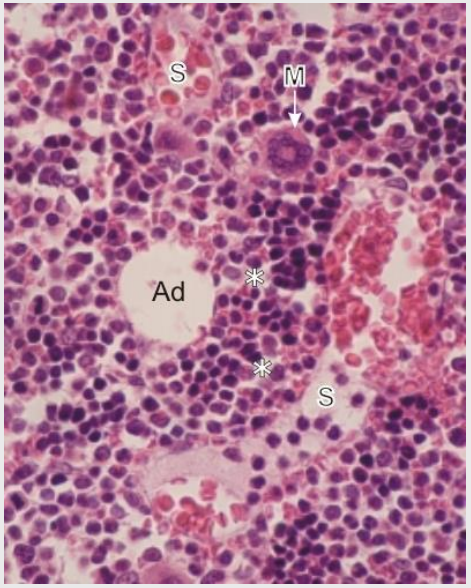
Medullar haematopoiesis – ADULTS.

Bone marrow examination – punction.
Bone marrow diseases.
Bone marrow transplantation.



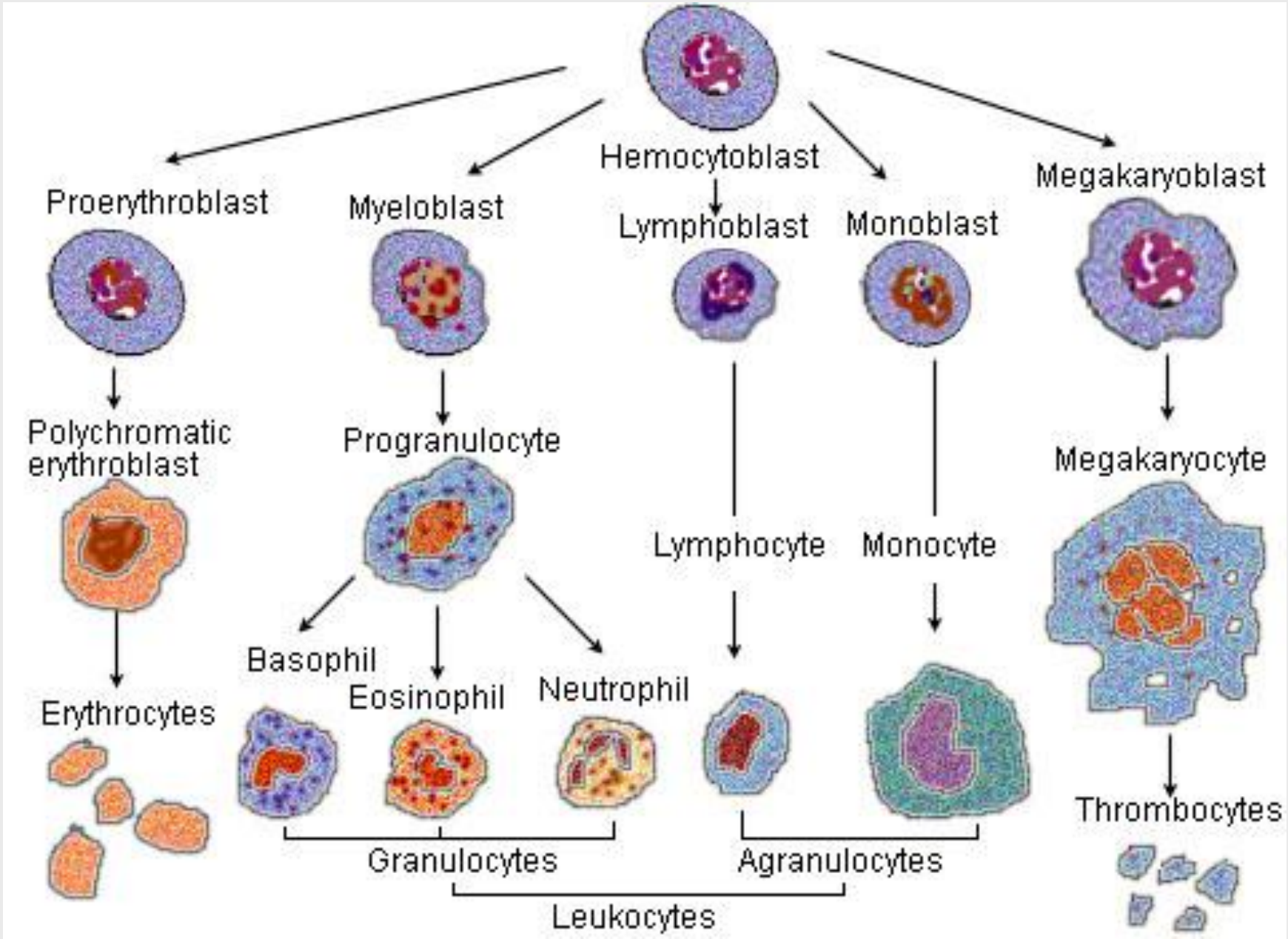


Section of yellow bone marrow. This bone marrow is yellow in its fresh state because of the abundance of yellowish adipocytes present. The hemopoietic (*) tissue is comparatively less abundant than in red bone marrow. The adipocytes, or fat cells, (Ad) appear as large circular clear spaces in this field. A megakaryocyte (M) and venous sinuses (S) are also labelled. Source: http://audilab.bmed.mcgill.ca/HA/html/blood_7_E.html



This bone marrow is referred to as red marrow because it contains few adipocytes, or fat cells, among an abundance of hemopoietic cells. It is difficult to identify the individual precursors of red and white blood cells because they are closely packed and condensed during the fixation of the tissue (*).
The following elements are identified: a megakaryocyte (M), which is a very large polyploid cell responsible for the production of blood platelets one adipocyte (Ad) two blood sinuses (S).
The walls of these vessels are the sites where newly formed erythrocytes and leukocytes pass from the connective tissue into the blood circulation.

Silverthorn, D. U. Human Physiology – an Integrated Approach. 6th. edition. Pearson Education, Inc. 2012.



Source: Wikimedia Commons

BLOOD CELLS

Cells	Cells /µl (average)	Normal range	Percent of total number of leukocytes
Leukocytes (total)	9000	3600 - 9600	White blood cell count
Granulocytes Neutrophiles	5400	3000 - 6000	42 – 75
Eozinophiles	275	150 - 300	1 - 4
Basophiles	35	0 - 100	0,4
Agranulocytes Lymphocytes	2750	1200 - 3400	20 - 50
Monocytes	540	110 - 590	1,7 – 9,3
Erythrocytes woman		$4,2 – 5,4 . 10^6$	
men		$4,5 - 6,3 . 10^6$	
Platelets	300 000	140000 – 440000	

RED BLOOD CELLS (ERYTHROCYTES)

		Men	Women
Hematocrit (Hct) (%)		47	42
Erythrocytes (RBC) (10^6/μl)		4,5 - 6,3 x10^6	4,2–5,4x10^6
Haemoglobin (Hb) (g/l)		140 - 180	120 - 160
Mean volume of ery (MCV) (fl)	= Hct x 10 / RBC (10^6/μl)	82 - 97	82 - 97
Mean content of Hb in ery (MCH) (pg)	= Hb x 10 / RBC (10^6/μl)	27 - 33	27 - 33
Mean concentration of Hb in ery (g/100ml)	= Hb x 100 / Hct	32 - 36	32 - 36
Mean diameter of ery (MCD) (μm)		7,5	7,5

Function of erythrocytes: blood gases transport

RED BLOOD CELL EXAMINATION

1. Red blood cell count

- normocytemia
- erytrocytopenia (oligocytemia)
- polyglobulia (polycytemia)

2. Concentration of haemoglobin

- anaemia

3. Hematocrit

SHAPE AND SIZE OF ERYTHROCYTES

Shape: biconcave disc

OPTIMAL RATIO OF SURFACE TO VOLUME!!!

By 30% larger surface in comparison with the cell of the same size but of round shape!!!

Anizocytosis – physiological, pathological. Price-Jones curve.

Size: 7,5 μm in diameter, 2 μm thickness – normocytes.

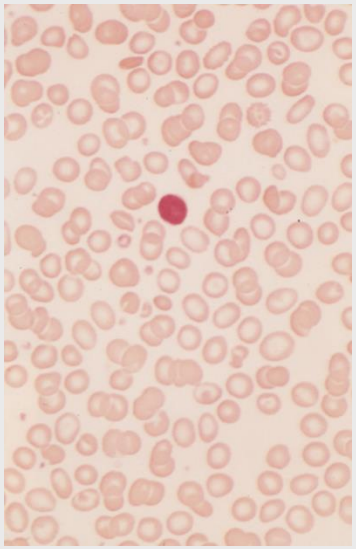
Microcytes (-osis): diameter below 6 μm, volume below 80 fl

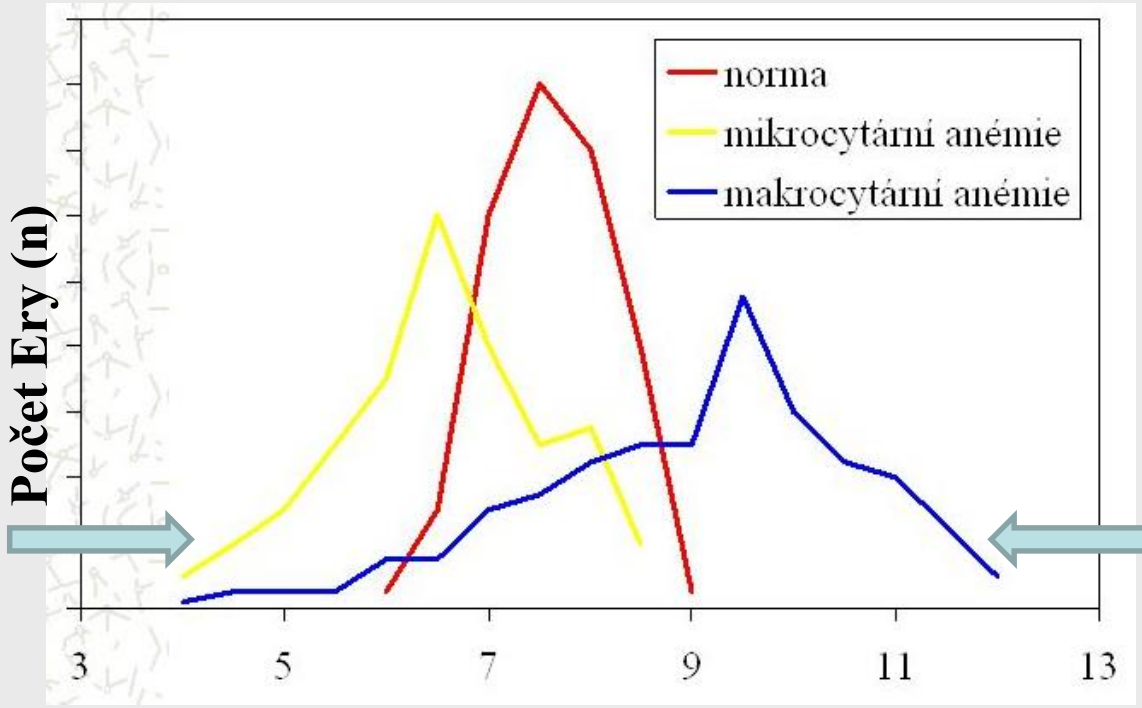
Macrocytes (-osis), megalocytes: diameter above 8.2 μm, volume above 95 fl

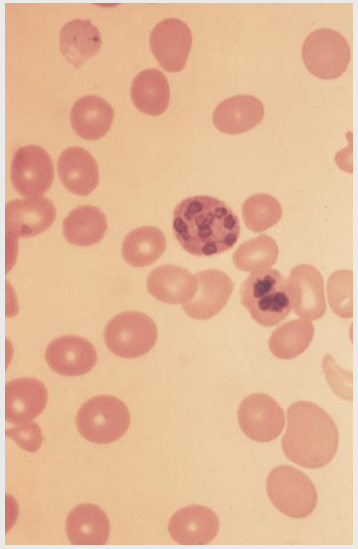
Amount of haemoglobin in one red blood cell: hypochromia (below 27 pg Hb/ery), normochromia, hyperchromia

Deformation of red blood cells. Fahraeus-Lindqvist effect.

SHAPE AND SIZE OF RED BLOOD CELLS
- Price-Jones curve



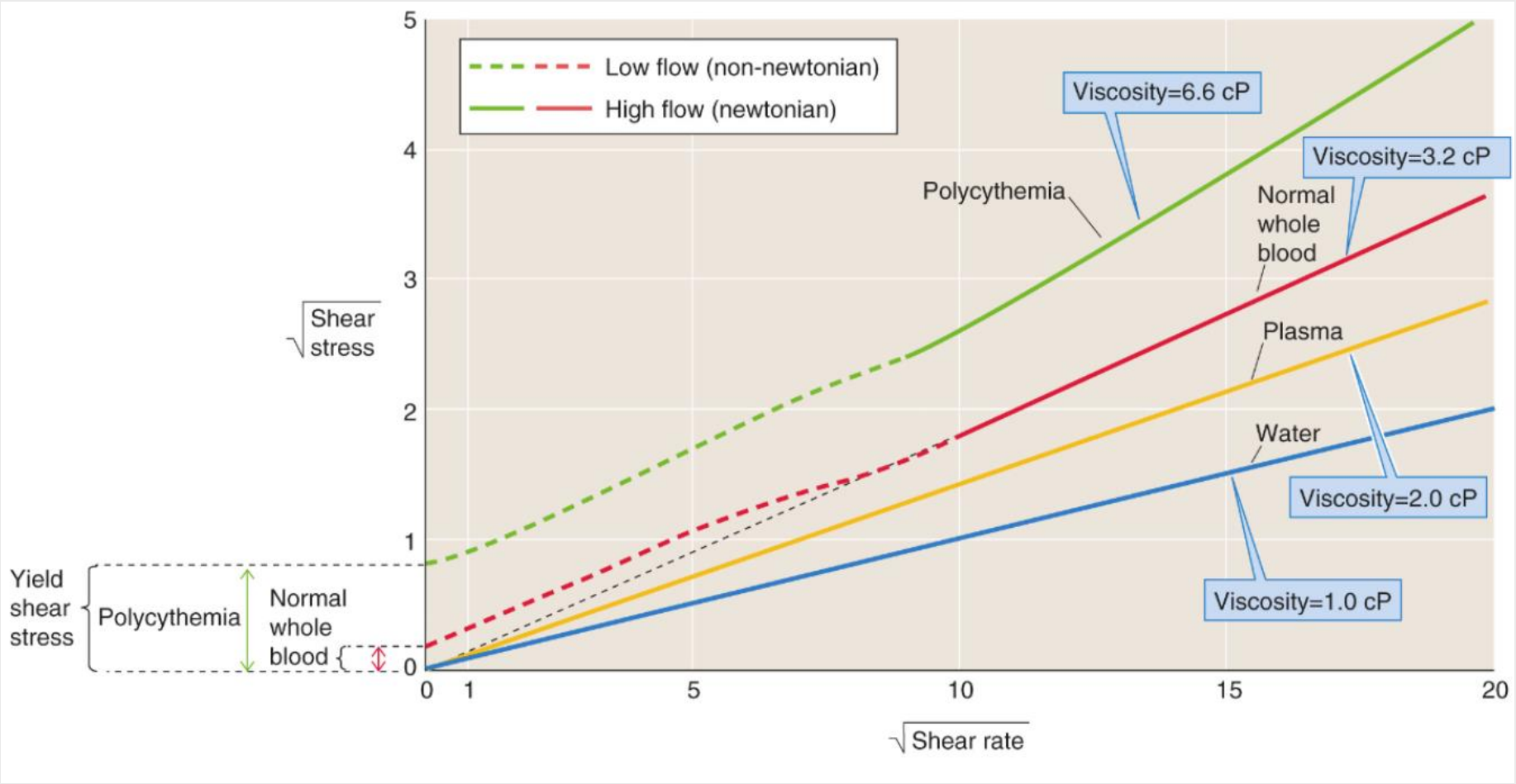




iron deficiency
blood loss
increased demands on iron
insufficient iron intake
insufficient iron resorption

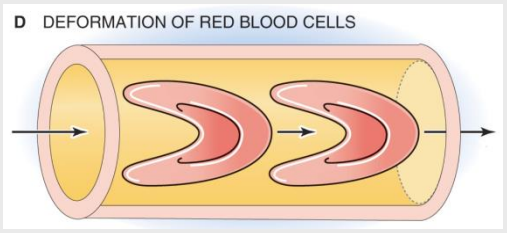
megaloblastic anemia
vitamin B12 deficiency
folate deficiency
DNA synthesis disorders

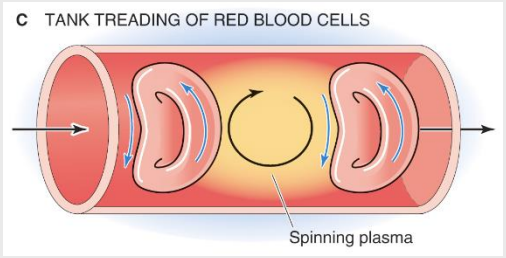
BLOOD VISCOSITY



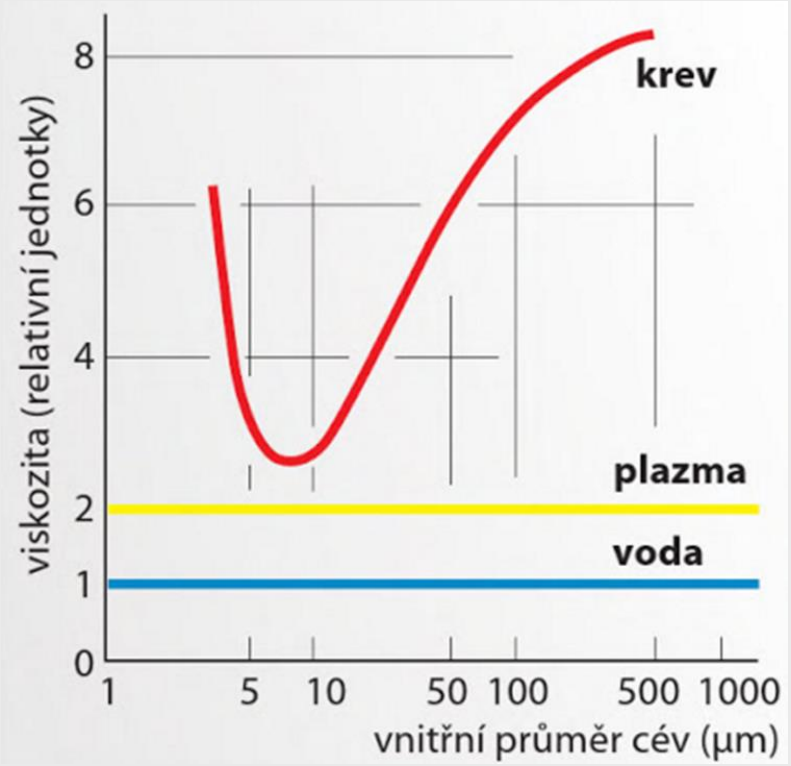
Plasma and serum behave almost like Newtonian fluids, whole blood like non-Newtonian fluids.

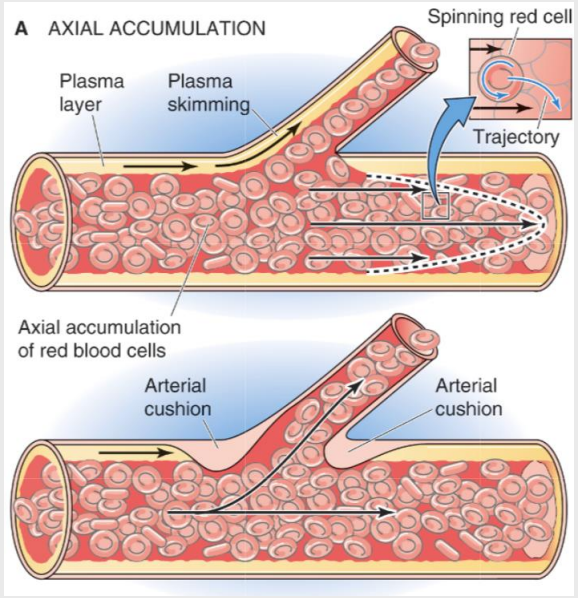
BLOOD VISCOSITY





viscosity





Inner diameter

Whole blood has an anomalous viscosity.

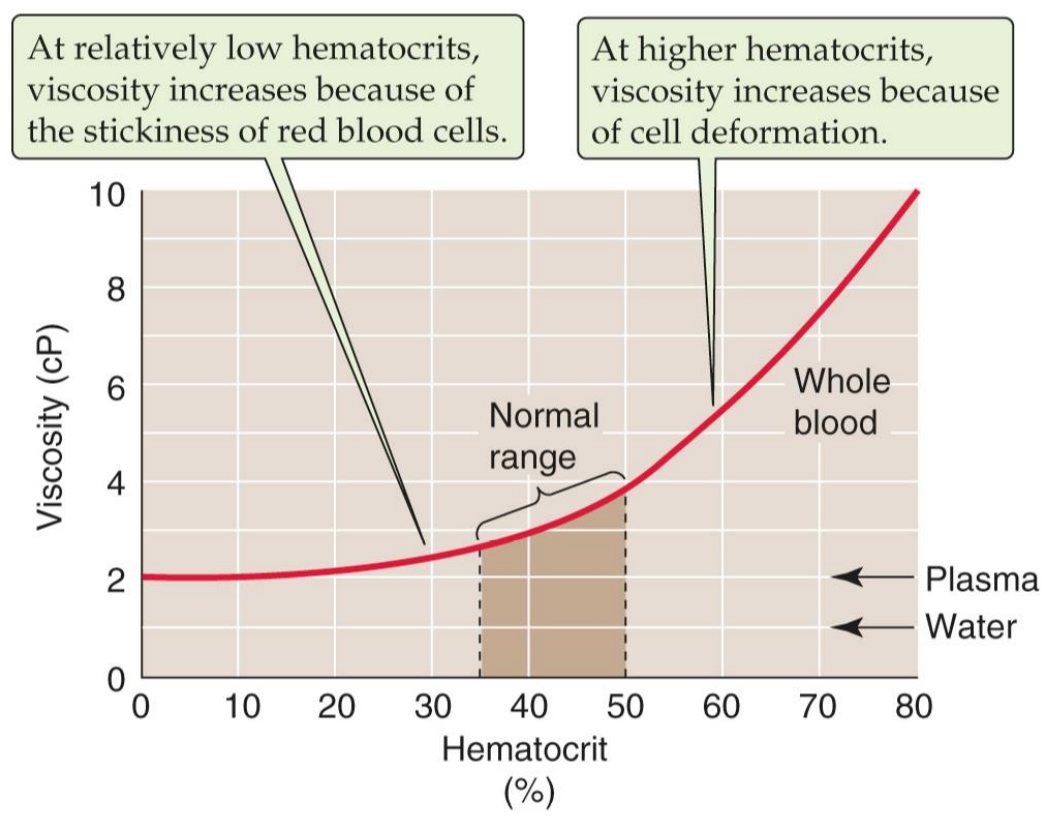
FACTORS AFFECTING BLOOD VISCOSITY

Fibrinogen

- Interactions with Ery (non-Newtonian fluid)
- Along with LDL
- Hyperfibrinogenemia - Ery clustering
- Note - age, smoking

Hematocrit

- Influence on direct and indirect interactions between Ery and between Ery and fibrinogen
- Increased hematocrit - tighter interactions between Ery = increased viscosity



FACTORS AFFECTING BLOOD VISCOSITY

Vessel diameter

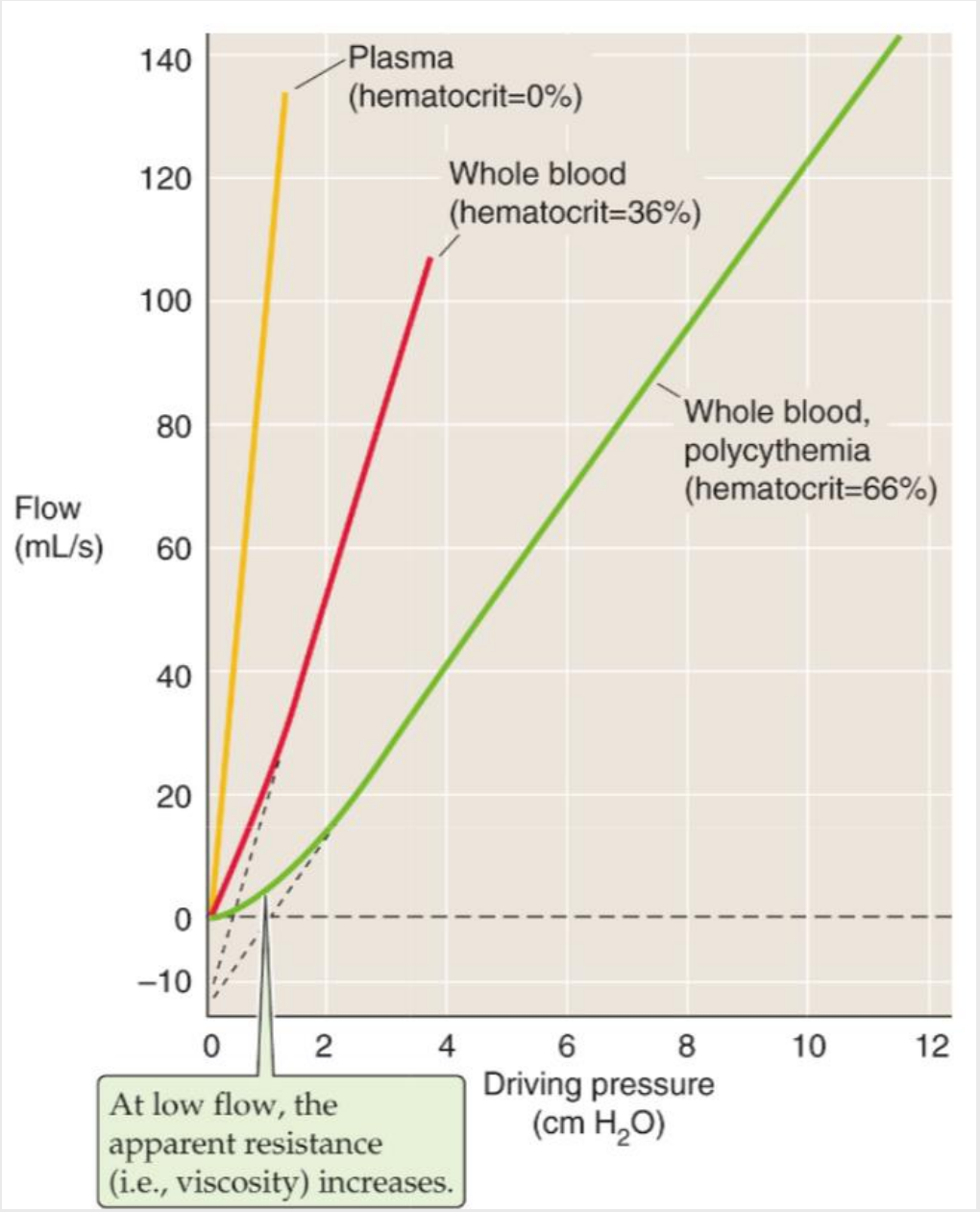
- Fahraeus-Lindqvist effect
- Axial accumulation of Era - local changes in viscosity
- Plasma behavior in relation to the vessel wall

Blood flow velocity

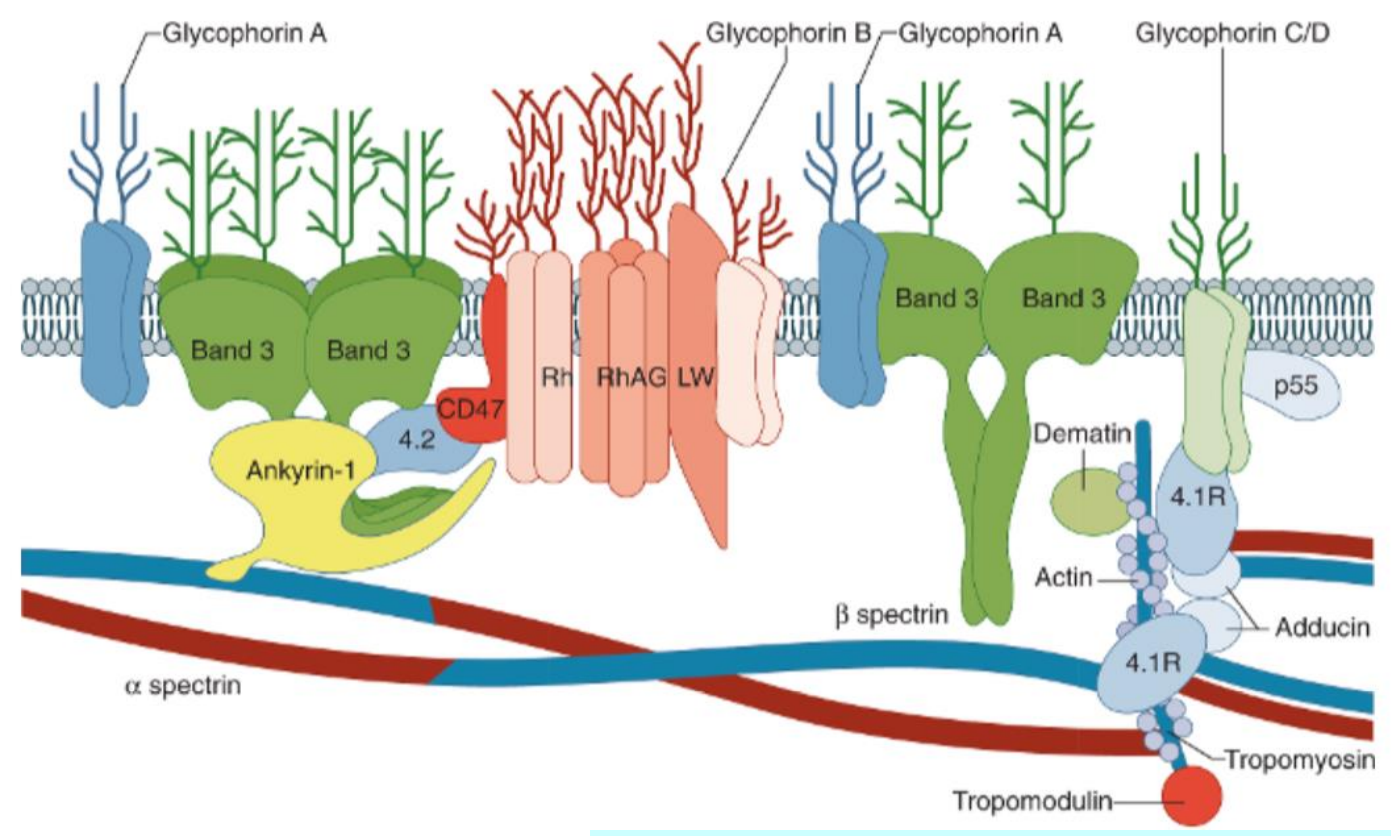
- Behavior of blood as a non-Newtonian fluid
- The "threshold force" required to set whole blood in motion
- Laminar flow and transport of the Ery through the center of the vessel

Temperature

- Under physiological conditions a negligible parameter
- Note cryoglobulins (HBC)



ERYTHROCYTE MEMBRANE



Provides

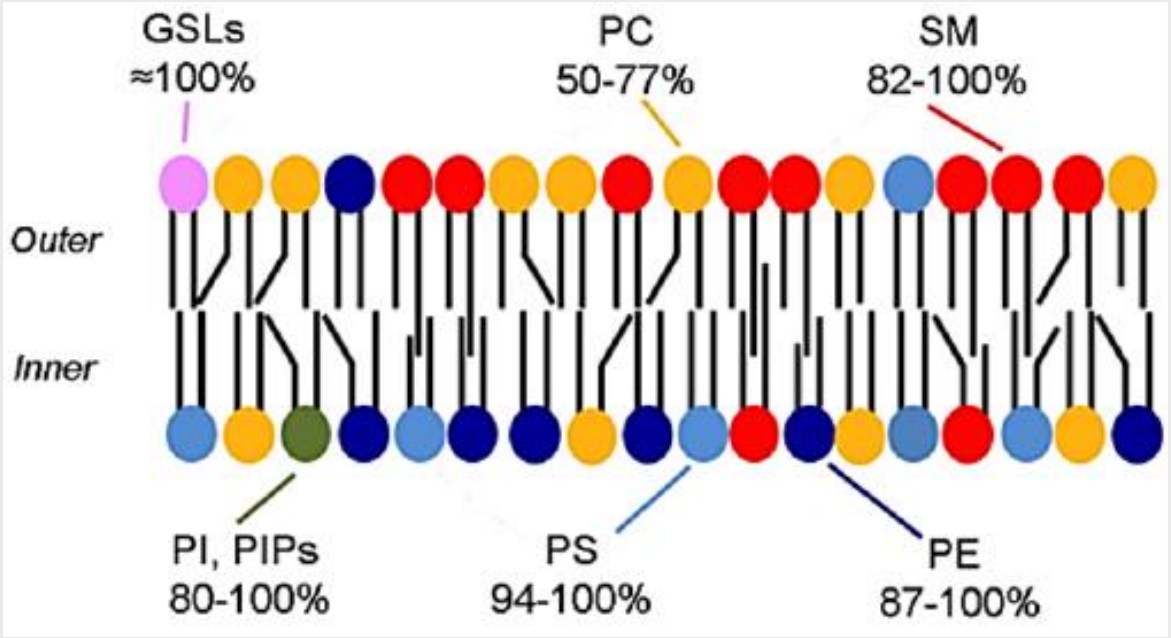
- Deformability of Ery
- Necessary stability (in circulation)

MP cca -9.0 mV

Stress of Ery

- Arterial system
- Microcirculation (change of shape, deformation, capillaries below 7.5 μm)
- Changes in tonicity, pH and pO_2

ERYTHROCYTE MEMBRANE



Membrane lipids

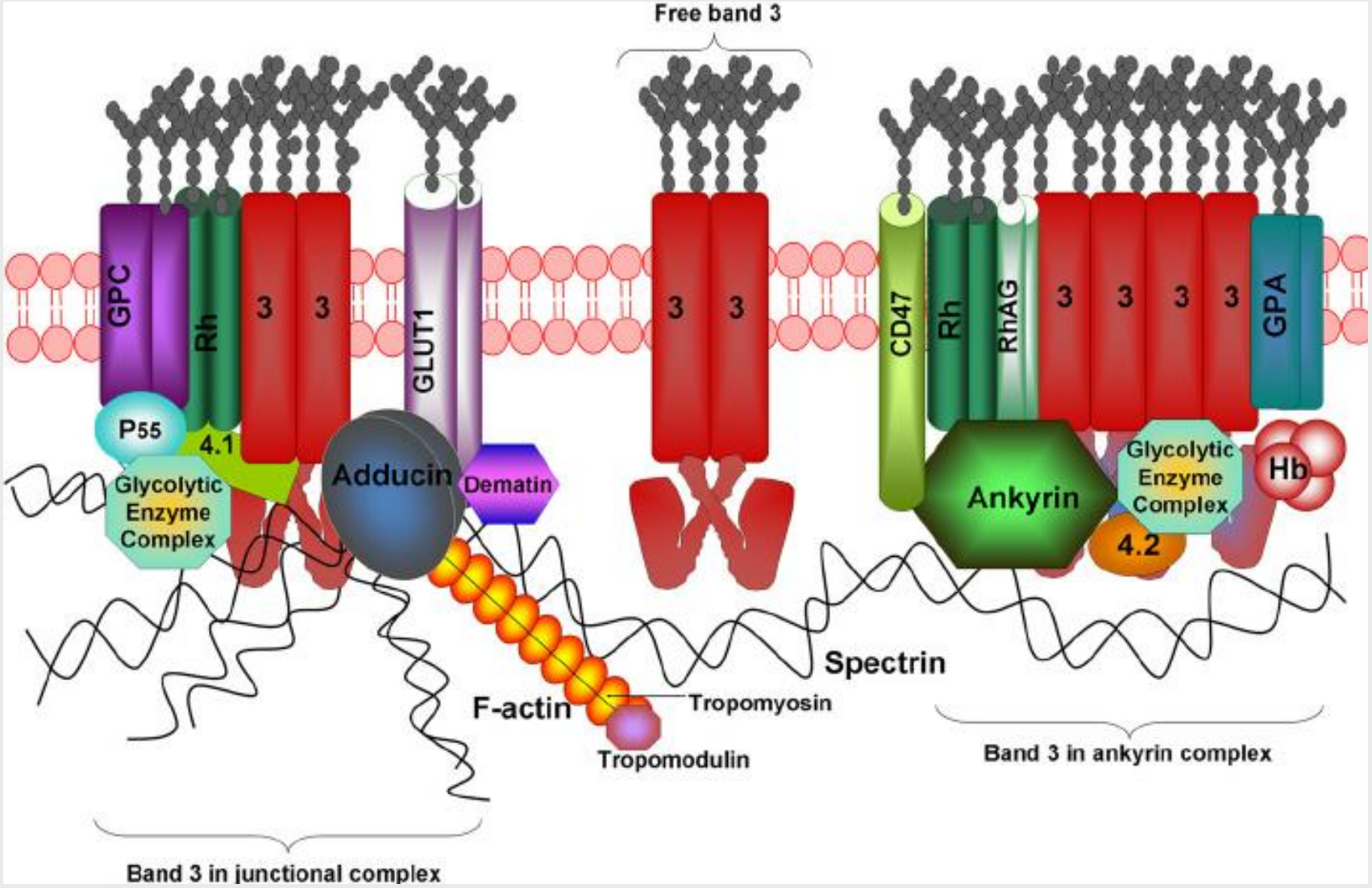
Phospholipid bilayer + glycolipids + cholesterol
- Asymmetric distribution
- External - phosphatidylcholine, sphingomyelin
- Internal - phosphatidylethanolamine, phosphatidylserine

Outward-facing sugar components - antigenic structures

Clinical overlap

- Loss of Ery membrane asymmetry
- Activation of prothrombin to thrombin conversion
- Signal for macrophages - elimination of Ery
- Thalassemia, diabetes mellitus

ERYTHROCYTE MEMBRANE



Membrane proteins

- About 12 major and 100 minor proteins; integral and peripheral

Transport proteins

- **Band 3 (Diego Blood group)**
  - mediating the exchange of chloride (Cl^-) for bicarbonate (HCO_3^-) across a plasma membrane
- **Aquaporin 1 = water channel (Colton Blood Group)**
- **GLUT1**
- **Jk antigen**
  - on a protein responsible for urea transport in the red blood cells and the kidney (aka human urea transporter 11- HUT11 or UT-B1)
- **Rh-associated glycoprotein (RHAG) (Rh Blood Group)**
  - an ammonia transporter protein
- **Na^+/K^+-ATPase**
- **Ca^{2+}-ATPase**
- **Na-K-Cl cotransporter**
- **Sodium-chloride symporter**
- **Chloride potassium symporter**
- **Potassium intermediate/small conductance calcium-activated channel (Gardos channel)**

Cell adhesion proteins

- **ICAM-4 (Landsteiner and Wiener Blood System)**
- **BCAM** = Basal cell adhesion molecule (**Lutheran blood group**)

Structural proteins

- Establish linkages with skeletal proteins
- Regulating cohesion
- Ankyrin-based macromolecular complex
- Protein 4.1R-based macromolecular complex
  - Protein 4.1 (Beatty's Protein)
  - Glycophorins C and D (**Gerbich Blood Group**)
  - XK (Kell blood group precursor) (**Kell Blood Group**)
  - RhD/RhCE (**Rh Blood Group**)
  - Duffy antigen/chemokine receptor (DARC)
  - Alpha-adducin
  - Dematin

Erythrocyte exceptions

They lack organelles

- no ATP production in oxidative phosphorylation
- no ability to replace damaged lipids and proteins (low metabolic activities, with no ability to synthesize new proteins or lipids)

Free radicals exposure

- haemoglobin autoxidation ($O_2^{\bullet -}$ release)
- a cell membrane rich in polyunsaturated fatty acids (susceptible to lipid peroxidation)
- deformation in tiny capillaries; catalytic ions leakage (cause of lipid peroxidation)

ERYTHROCYTE METABOLISM AND THEIR SPECIAL FEATURES

They lack organelles (practically zero ability to regenerate, no proteosynthesis)

Exposure to ROS (hemoglobin autooxidation, Ery deformation as a source of ROS, lipid peroxidation)

Carbonic anhydrase I and II (CA I and II – interconversion of CO_2 a HCO_3^-)

ATP as a vasodilator

Glycolysis as a source of ATP and 2,3-BPG (90% of Glu consumption)

Pentose pathway as a source of NADPH (10% Glu consumption)

Synthesis of GSH (up to 2mM conc., GSH / GSSG, GR - antioxidant system)

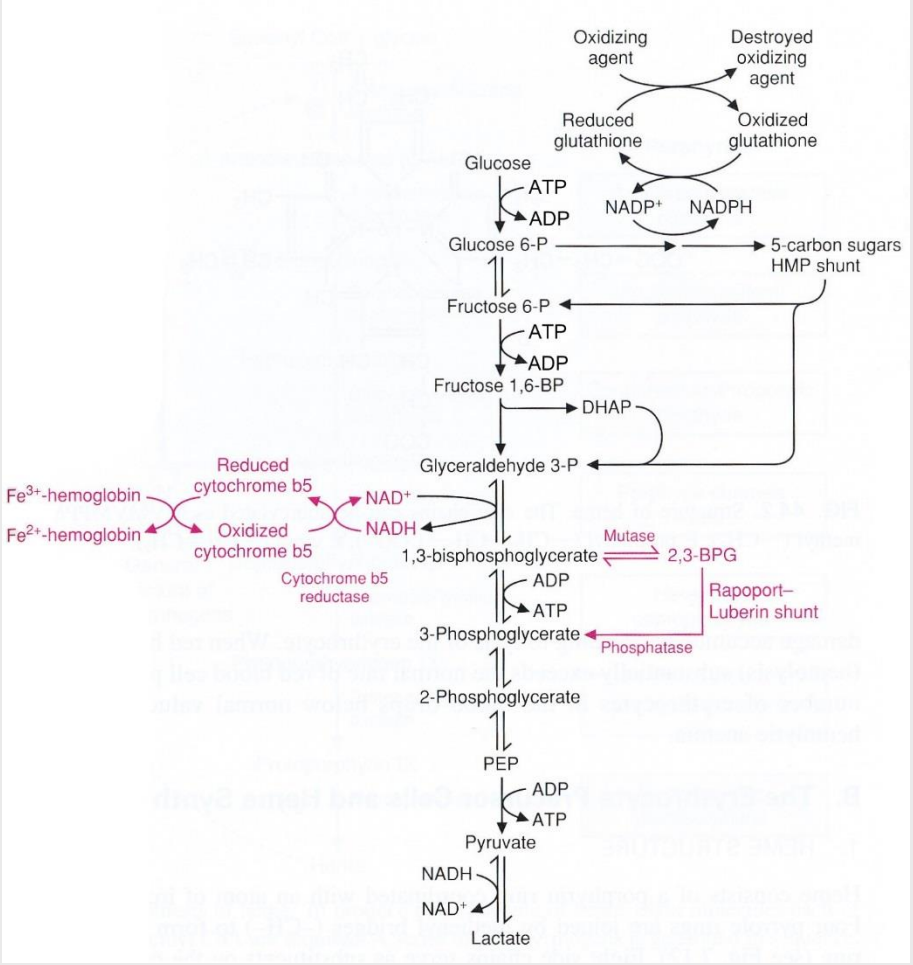
Erythrocyte metabolism

1. **Glucose as a source of energy** (GLUT1 transporter, insulin-independent)

2. **Glycolysis generates ATP and 2,3-bisphosphoglycerate** (the specific binding of 2,3-BPG to deoxyhemoglobin decreases the oxygen affinity of hemoglobin and facilites oxygen release in tissues)

3. **The pentose phosphate pathway produces NADPH**

4. **Glutathione synthesis - the antioxidant defence system**



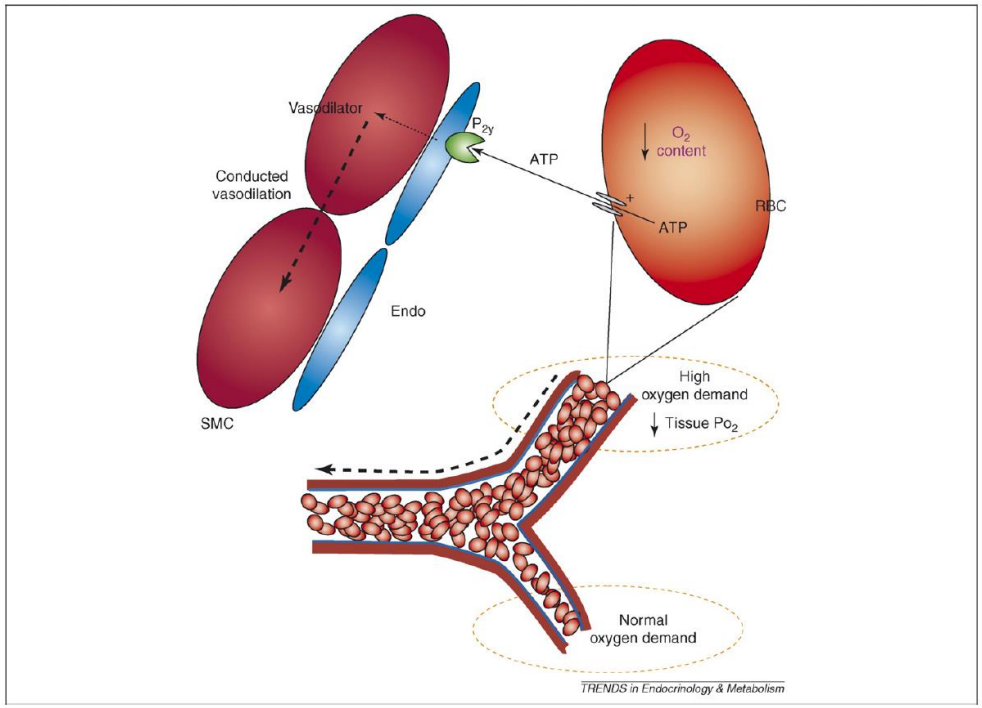


Figure 1. Cascade of events initiated by the entrance of erythrocytes into a tissue region (dashed oval) in which oxygen demand exceeds oxygen supply. [For clarity, a single erythrocyte (RBC) is enlarged along with the associated vascular cells to show the events that occur following the entrance of an erythrocyte into the region of tissue with high oxygen demand.] When oxygen supply does not meet oxygen demand, tissue oxygen tension (PO_2) decreases. This decrease in tissue PO_2 causes the hemoglobin oxygen content of the erythrocytes that perfuse the tissue region to decrease proportionally. This decrease in oxygen content initiates a series of events resulting in the release of ATP from the erythrocyte. The ATP then diffuses to the endothelium (Endo) where it binds to purinergic (P_{2y}) receptors resulting in the production of vasoactive mediators, either within the endothelium or the smooth muscle (SMC), which initiate vasodilation. This vasodilation is conducted (dashed arrow) in a retrograde fashion increasing flow and thus oxygen supply to the tissue region in need.

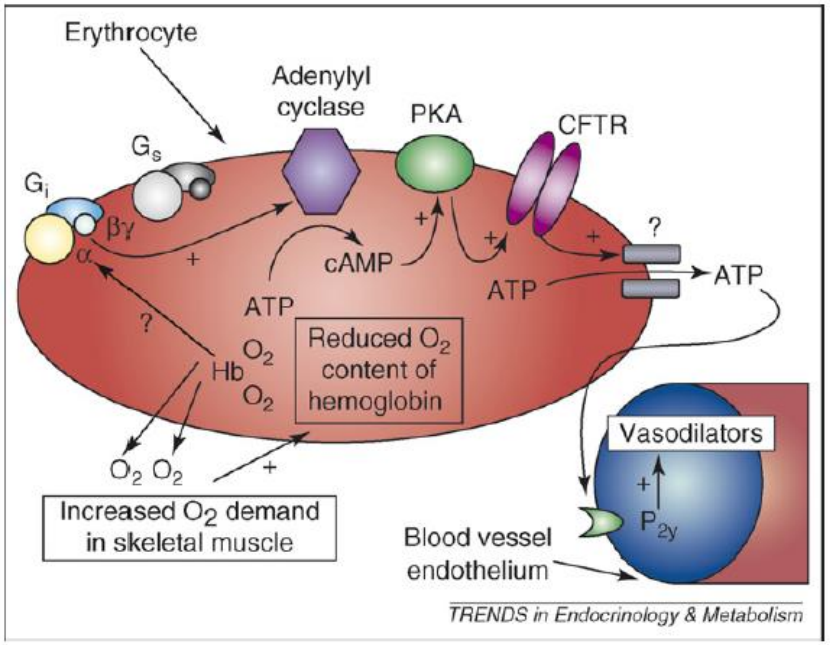


Figure 2. Proposed pathway for regulated ATP release from erythrocytes in response to passage of these cells through areas of increased oxygen demand in skeletal muscle. The increase in oxygen demand leads to oxygen release from hemoglobin within the erythrocyte. Consequently, hemoglobin oxygen content decreases resulting in activation of the heterotrimeric G protein, Gi, leading to ATP release. ATP released from the erythrocyte can bind to purinergic receptors (P_{2y}) on the vascular endothelium resulting in the release of vasodilators and, ultimately, an increase in blood flow (oxygen delivery). Abbreviations: Gi and Gs = heterotrimeric G proteins - i = inhibitory, s = stimulatory; ATP = adenosine 5′-triphosphate; cAMP = 3′5′-cyclic adenosine monophosphate; Hb = hemoglobin; PKA = protein kinase A; CFTR = cystic fibrosis transmembrane conductance regulator; ? = an as yet unidentified mechanism; P_{2y} = P_{2y} purinergic receptor; ± = stimulation.

Sprague RS, Stephenson AH, Ellsworth ML: **Red not dead: signaling in and from erythrocytes.** ***TRENDS in Endocrinology and Metabolism 2007, 18(9):350-355.***

MORPHOLOGICAL VARIATIONS OF ERYTHROCYTES

Poikilocytes – drop-like erythrocytes

Schizocytes – fragmented erythrocytes

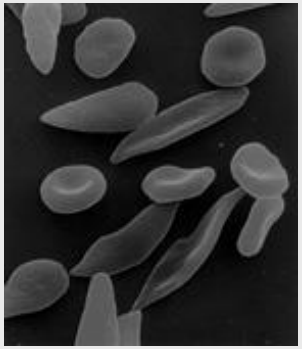
Spherocytes – volume normal, diameter smaller, thickness bigger

Eliptocytes – ecliptic shape

Leptocytes – thin, centrally concentrated haemoglobin

(thalasemia, after splenectomy)

Akantocytes – prickly prominences



FRAGILITY OF ERYTHROCYTES

Haemolysis – destruction of red blood cell membrane.

Types of haemolysis:
a) physical
b) chemical
c) osmotic
d) biological (toxic)
e) immunological

Spherocytosis
- disorders of protein net responsible for shape and elasticity of erythrocyte membrane – actin, ankyrin, spectrin.
Disorders of glucose-6-phosphate-dehydrogenase .

Erythrocytes life span: 120 days, role of lien (double circulation), splenectomy.
Reticulocytes.

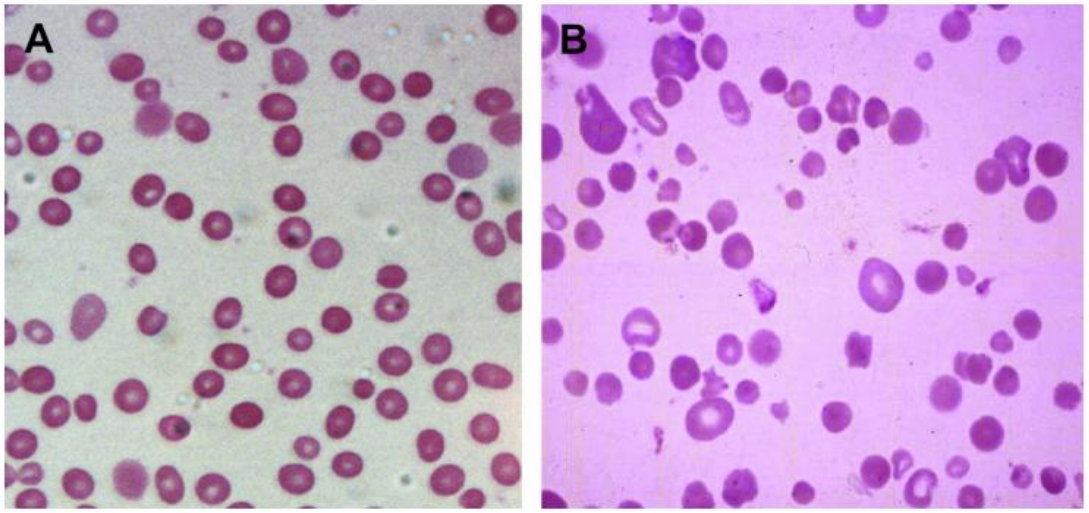


Fig. 2. Peripheral blood smears in hereditary spherocytosis. (*A*) Typical hereditary spherocytosis. Characteristic spherocytes lacking central pallor are seen. (*B*) Severe, recessively inherited spherocytosis. Numerous small, dense spherocytes and bizarre erythrocyte morphology with anisocytosis and poikilocytosis associated with severe hemolysis are seen.

Table 1
Classification of hereditary spherocytosis

	Carrier	Mild Spherocytosis	Moderate Spherocytosis	Severe Spherocytosis[a]
Hemoglobin (g/dL)	Normal	11–15	8–12	6–8
Reticulocytes (%)	≤3	3–6	≥6	≥10
Bilirubin (mg/dL)	0–1	1–2	≥2	≥2
Spectrin content (% of normal)	100	80–100	50–80	40–60
Peripheral smear	Normal	Mild spherocytosis	Spherocytosis	Spherocytosis
Osmotic fragility fresh blood	Normal	Normal or slightly increased	Distinctly increased	Distinctly increased
Incubated blood	Slightly increased	Distinctly increased	Distinctly increased	Distinctly increased

[a] Values in untransfused patients.

From Eber SW, Armbrust R, Schroter W. Variable clinical severity of hereditary spherocytosis: relation to erythrocytic spectrin concentration, osmotic fragility, and autohemolysis. J Pediatr 1990;117:409–16.

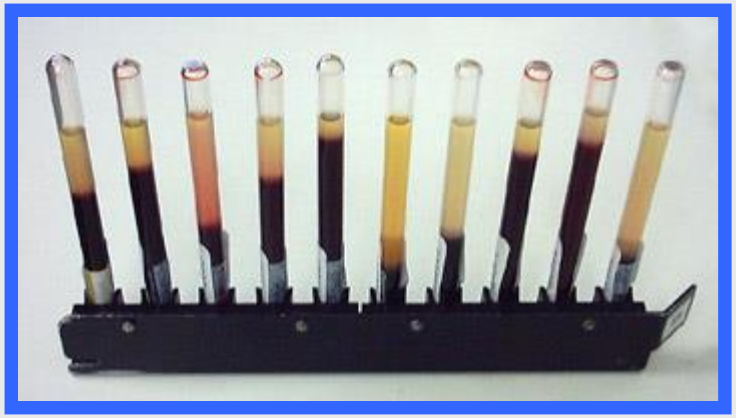
Gallagher PG: **Abnormalities of the Erythrocyte Membrane.** ***Pediatric Clinics of North America 2013, 60(6):1349-+.***

ERYTHROCYTE SEDIMENTATION

Sedimentation rate indirectly corresponds to suspension stability of blood.

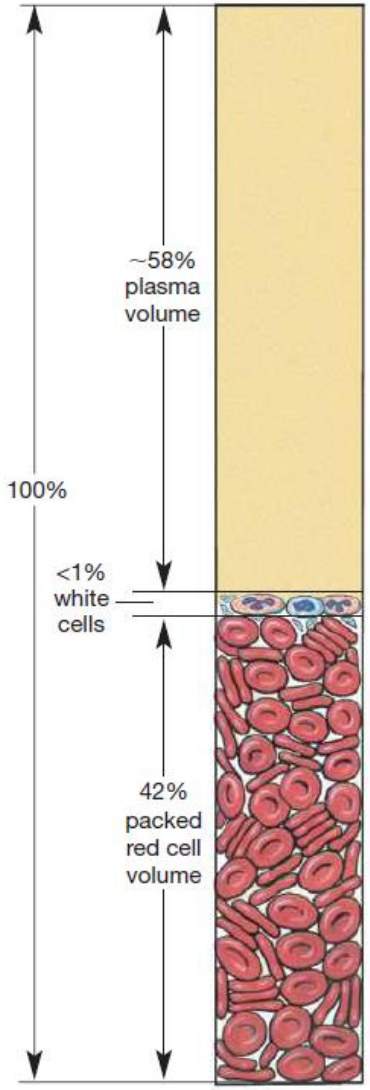
Method of Fahreus-Westergren (FW).

Physiological values: men – women
Units: mm/10min, 1 hr, 2 hrs, 24 hrs
Physiological causes of increased sedimentation.
Pathological causes of increased sedimentation.



THE BLOOD COUNT

This table lists the normal ranges of values.



	MALES	FEMALES
Hematocrit		
Hematocrit is the percentage of total blood volume that is occupied by packed (centrifuged) red blood cells.	40–54%	37–47%
Hemoglobin (g Hb/dL* whole blood)		
The hemoglobin value reflects the oxygen-carrying capacity of red blood cells. (*1 deciliter (dL) = 100 mL)	14–17	12–16
Red cell count (cells/μL)		
A machine counts erythrocytes as they stream through a beam of light.	$4.5–6.5 \times 10^3$	$3.9–5.6 \times 10^3$
Total white count (cells/μL)		
A total white cell count includes all types of leukocytes but does not distinguish between them.	$4–11 \times 10^3$	$4–11 \times 10^3$
Differential white cell count		
The differential white cell count presents estimates of the relative proportions of the five types of leukocytes in a thin blood smear stained with biological dyes.		
Neutrophils	50–70%	50–70%
Eosinophils	1–4%	1–4%
Basophils	<1%	<1%
Lymphocytes	20–40%	20–40%
Monocytes	2–8%	2–8%
Platelets (per μL)		
Platelet count is suggestive of the blood's ability to clot.	$150–450 \times 10^3$	$150–450 \times 10^3$

Fig. 16.3

Silverthorn, D. U. Human Physiology – an Integrated Approach. 6th. edition. Pearson Education, Inc. 2012.

Table 2. Factors causing false changes in Erythrocyte Sedimentation Rate

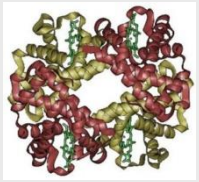
Factors causing false increases	Factors causing false decreases
Increased fibrinogen, globulin, cholesterol levels	Cachexia
High room temperature	Coagulation of the blood sample
Macrocytic anemia	Increase in bile salts
Menstruation	Increase in phospholipids
Pregnancy	Making the sedimentation sample wait more than two hours
Tilting or lying down of the ESR tube	Increase in adrenal steroids
Drugs: Dextrane, methyldopa, methysergide, penicillamine, procainamide, teophylline, trifluoperidole, vitamin A	Hypofibrinogenemia
	Hyperglycemia
	Hyperalbuminemia
	Leukocytosis
	Microcytic anemia
	Drugs: ACTH, cortisone, ethambutol, quinine, salicylates

(Adapted from A Textbook of Natural Medicine, Pizzorno and Murray, 1992)

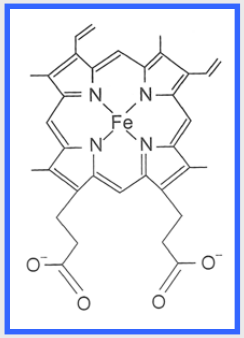
Table 3. Factors affecting Erythrocyte Sedimentation Rate (ESR)

Increased ESR	Decreased ESR
Acute Heavy Metal Poisoning	Congestive heart failure
Collagen Vascular Disease	Polycythemia
Carcinomas	Sickle Cell Anemia
Cell or tissue injury	
Gout arthritis	
Infections	
Inflammatory disorders	
Leukemia	
Myocardial infarction	
Nephritis	
Syphilis	

(Adapted from A Textbook of Natural Medicine, Pizzorno and Murray, 1992)



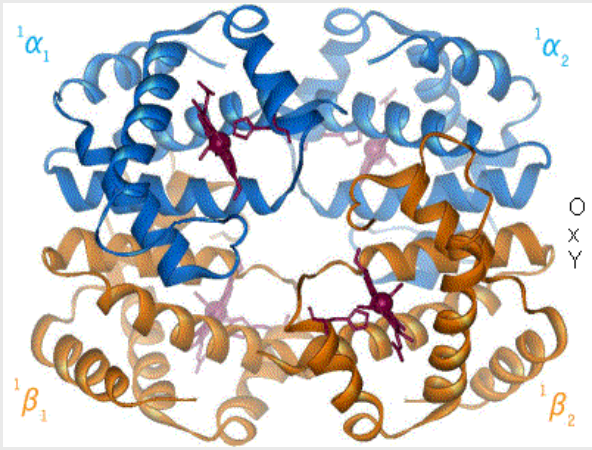
HAEMOGLOBIN



Red pigment transporting oxygen.
Protein, 64 450, 4 subunits.
Hem – derivative of porphyrine containing iron, conjugated with polypeptides (globin).

Embryonic haemoglobin: Gower I a Gower II ($\tau 2\varepsilon 2$, $\alpha 2\varepsilon 2$), Portland
Fetal haemoglobin: Hb F, $\beta 2\gamma 2$, weaker binding of 2,3 DPG
Adult haemoglobin: Hb A, $\alpha 2\beta 2$ (141/146)

Forms of haemoglobin:
oxyhaemoglobin - O_2
carbaminohaemoglobin – CO_2
methaemoglobin – Fe^{3+} in hem
carboxyhaemoglobin – CO



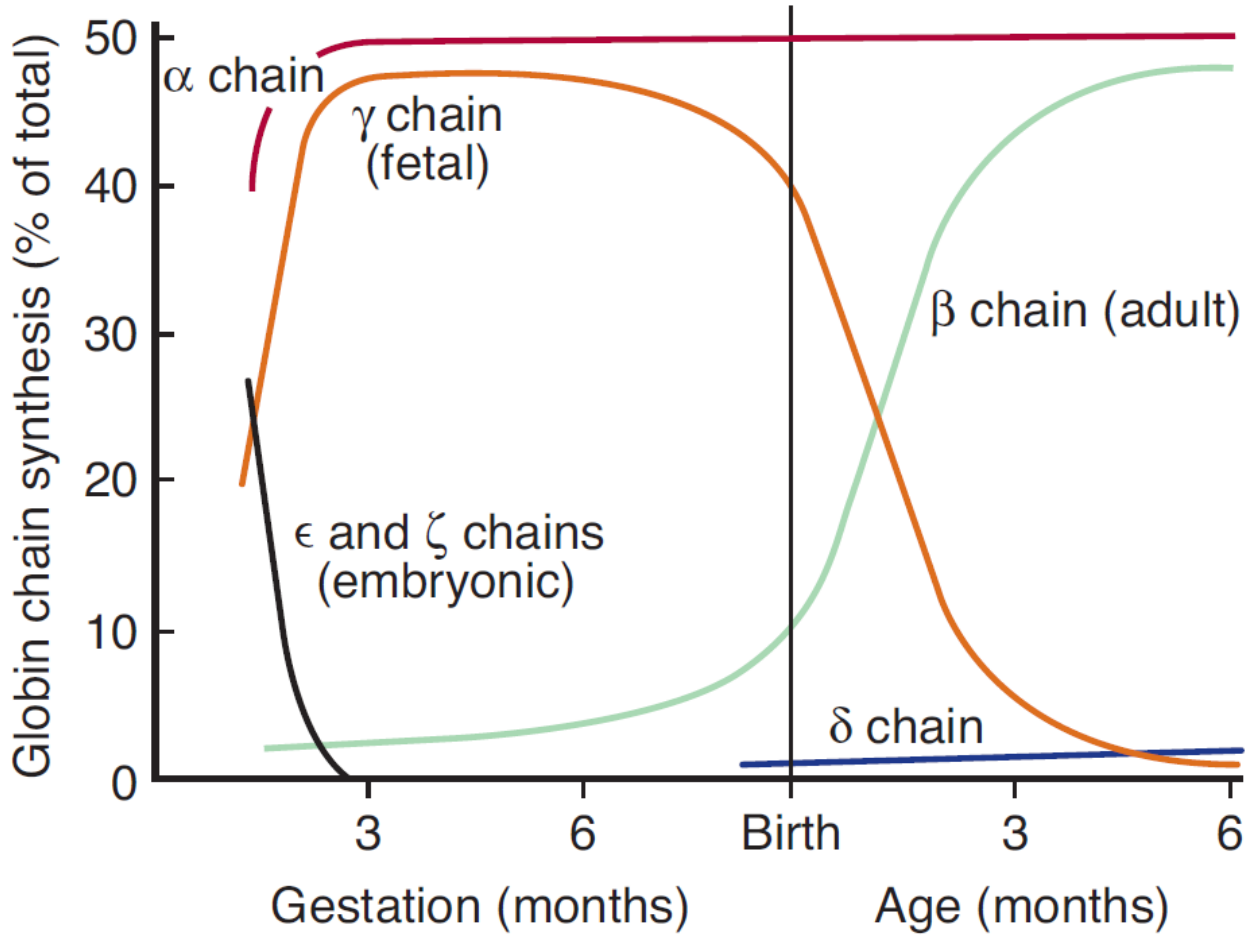
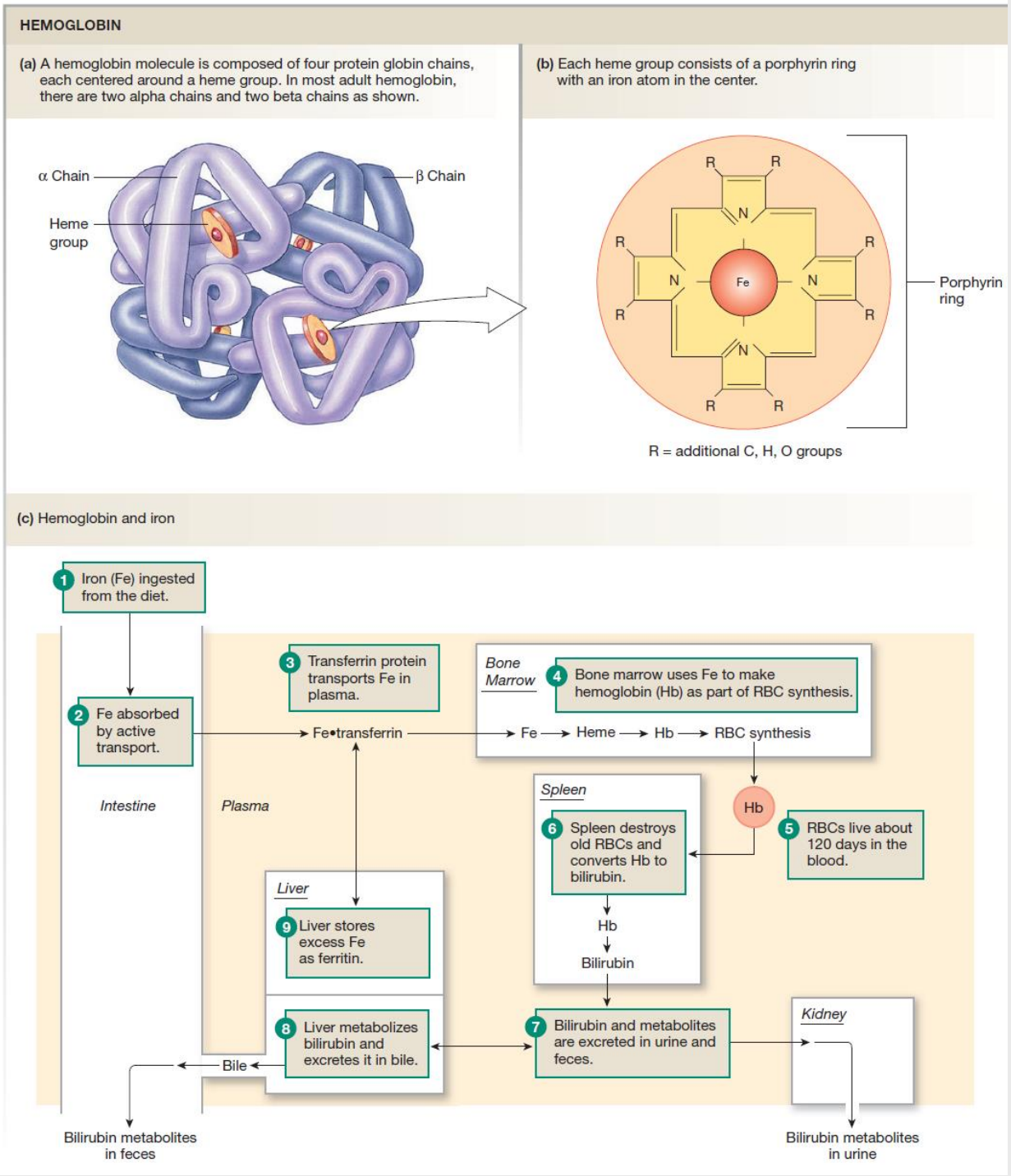
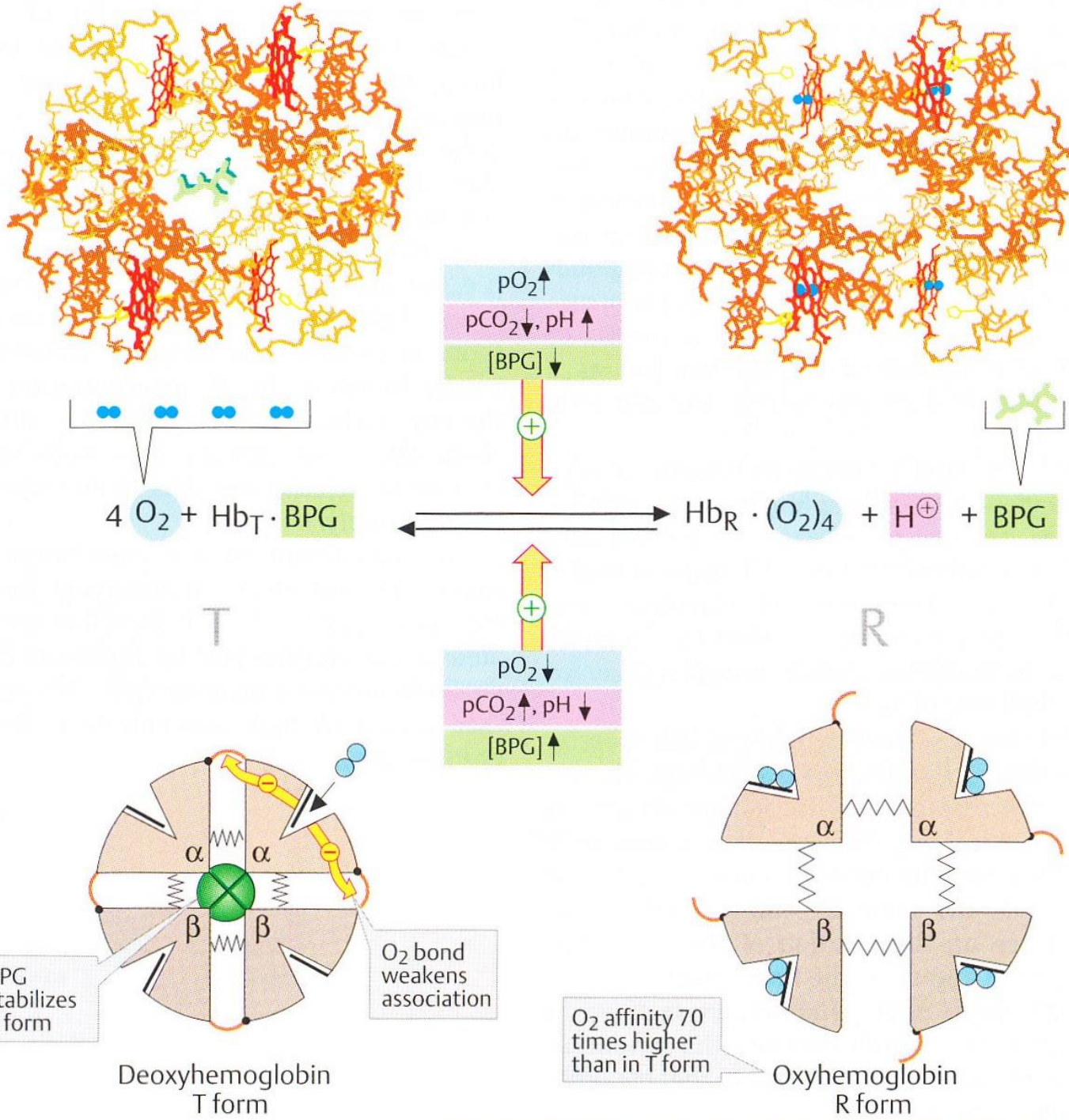


FIGURE 32–8 **Development of human hemoglobin chains.**



Silverthorn, D. U. Human Physiology – an Integrated Approach. 6th. edition. Pearson Education, Inc. 2012.


pO2↑
pCO2↓, pH↑
[BPG]↓
4 O2 + HbT · BPG
HbR · (O2)4 + H⊕ + BPG
T
R
pO2↓
pCO2↑, pH↓
[BPG]↑
α
α
β
β
BPG stabilizes T form
O2 bond weakens association
Deoxyhemoglobin T form
O2 affinity 70 times higher than in T form
Oxyhemoglobin R form

Abnormalities of haemoglobin production

- haemoglobinopathy (abnormal structure of chains)
- thalasemia (lower production of normal chains)
- Sickle cell anaemia (Hb J)

Synthesis and destruction of haemoglobin

Hem: glycin a succinyl-CoA
Globin: AMK
Hem - globin: biliverdin, bilirubin (lumirubin – photo-therapy), bil

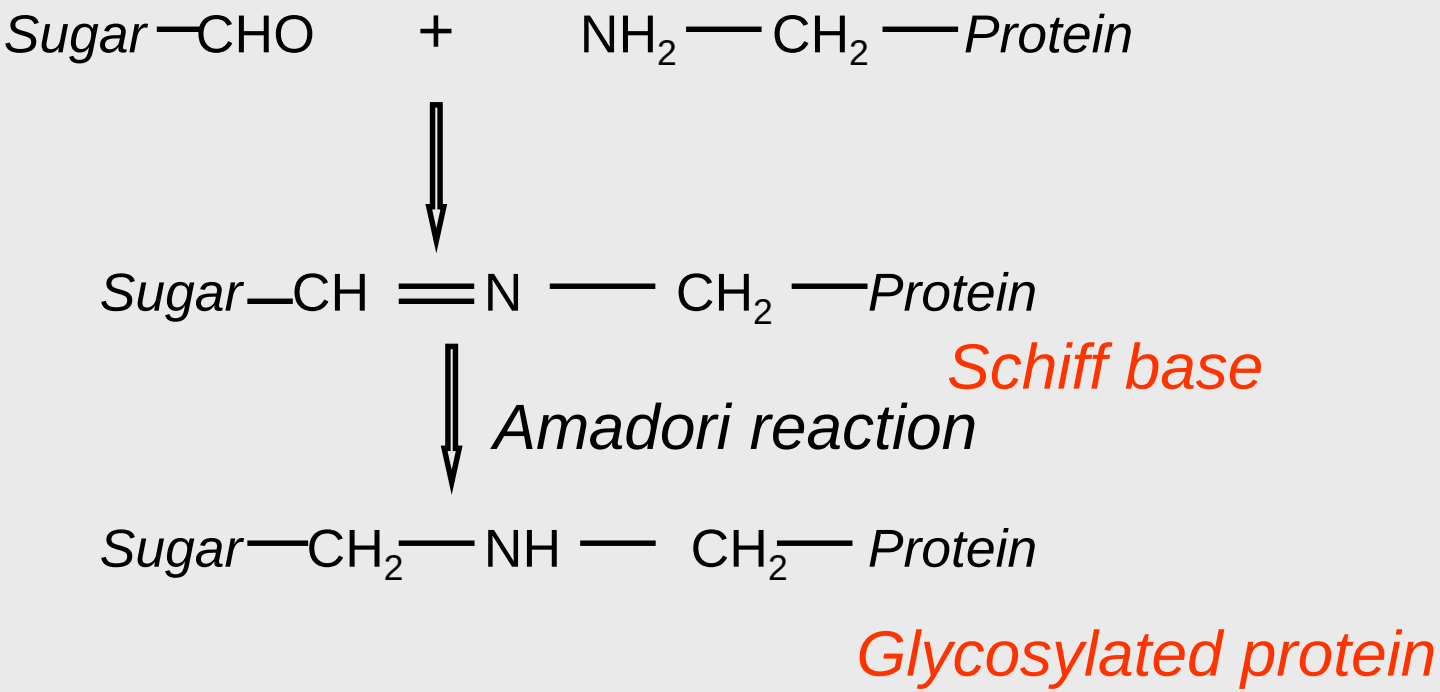
TABLE 32–3 **Partial amino acid composition of normal human β chain, and some hemoglobins with abnormal β chains.[a]**

	Positions on Polypeptide Chain of Hemoglobin						
Hemoglobin	**1 2 3**	**6 7**	**26**	**63**	**67**	**121**	**146**
A (normal)	Val-His-Leu	Glu-Glu	Glu	His	Val	Glu	His
S (sickle cell)		Val					
C		Lys					
$G_{San\ Jose}$		Gly					
E			Lys				
$M_{Saskatoon}$				Tyr			
$M_{Milwaukee}$					Glu		
O_{Arabia}						Lys	

[a]Other hemoglobins have abnormal α chains. Abnormal hemoglobins that are very similar electrophoretically but differ slightly in composition are indicated by the same letter and a subscript indicating the geographic location where they were first discovered; hence, $M_{Saskatoon}$ and $M_{Milwaukee}$.

Clinical aspects - Glycosylated haemoglobin (HbA_1)

- formed by hemoglobin's exposure to high plasma levels of glucose
- non-enzymatic glycolysation (glycation)- sugar bonding to a protein
- normal level HbA_1- 5%; a buildup of HbA_1- increased glucose concentration
- the HbA_1 level is proportional to average blood glucose concentration over previous weeks; in individuals with poorly controlled diabetes, increases in the quantities of these glycated hemoglobins are noted (patients monitoring)



ERYTHROPOETIN

Glycoprotein, 39 000, α2-globulin.
Recombinant erythropoetin.
Small amount in plasma, urine, lymph, foetal blood.
Inactivation: liver
Origin: kidneys (85-90%) – endothelial cells of peri-tubular capillaries in kidney core, liver (10-15%)
Stimulation of release: tissue hypoxia of any origin, alkalosis, cobalt salts, androgens, catecholamines (β-receptors)
Effects:
Erythropoetin responsive cell – differentiation into erythroid line: increase of synthesis of nucleic acids, increase of iron absorption in erythroid cells, stimulation of cells release from bone marrow into circulation

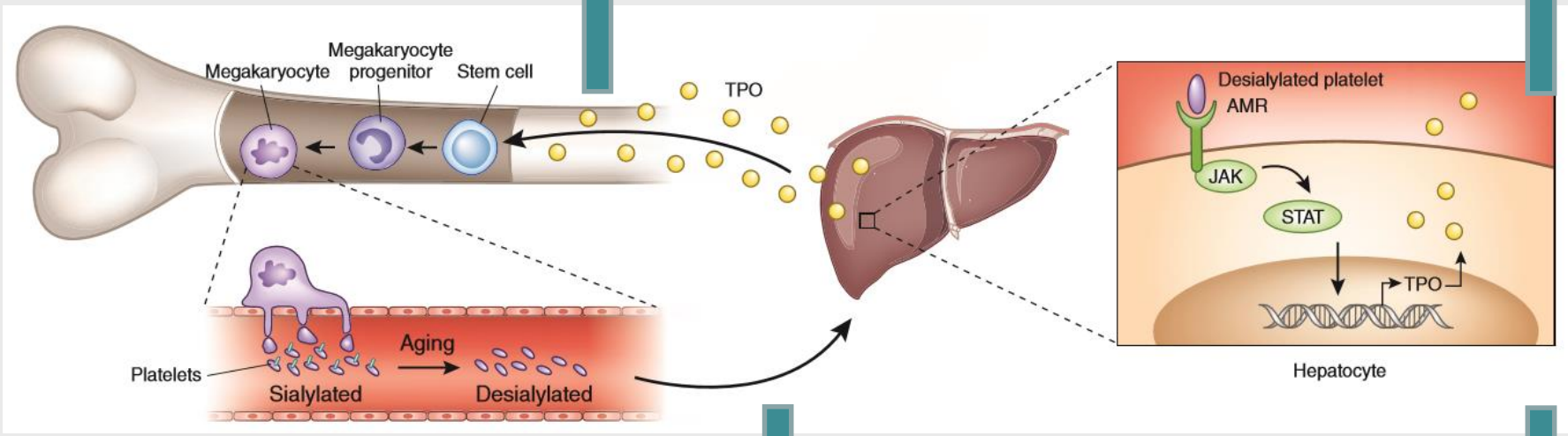
Acclimation – adaptation to high altitude

Thrombopoietin (THPO)

- Binding of TPO to R (c-Mpl) platelets and megakaryocytes
- Internalization of receptors
- "Clearance" of TPO and reduction of circulating TPO levels

Characteristics
- Glycoprotein
- Liver, kidneys (PCT), bone marrow, skeletal muscle

- Constitutive production of TPO



- Decrease in platelet count = increase in circulating TPO levels

- Platelet aging = desialylation
- Desialylation due to infection?
- "Detection" of Gal oligosaccharide residues
- AMR receptor

ERYTHROPOESIS

Substances affecting erythropoesis

Need of copper

Ceruloplasmin – binding protein (α2-globulin) with ferroxidase activity. Oxidation of Fe^{2+} to Fe^{3+} is necessary for binding of iron to transferrin.

Need of cobalt

Part of vitamin B_{12} molecule.

Vitamin B12 (cyancobalamin)

Produced by bacteria in GIT.

Source: liver, kidneys, meet, milk products…

Resorption: necessity of s.c. **intrinsic factor** secreted by parietal cells of gastric fundus and body. Bound to transcobalamins in blood.

Stored in liver, pancreas, kidneys, brain, myocardium.

Function: synthesis of nucleic acids, co-factor in conversion of ribonucleotids to deoxyribonucleotids, production of metabolic active forms of folic acid

NECESSARY FOR NORMAL DIVISION AND MATURATION OF RED BLOOD CELL LINE ELEMENTS.

Symptoms of anaemia after years only!!!

Pernicious anaemia.

Folic acid (pteroylglutamic)

Produced by higher plants and micro-organisms.

Source: green vegetables, yeast, liver, kidneys…

Function: part of co-enzymes during synthesis of DNA, participation in cell division and differentiation

Deficiency: deficient nutrition, treatment with cytostatics (methotrexate)

Symptoms of anaemia already after couple of months!!!

Macrocyte hyperchromic anaemia.

Other vitamins

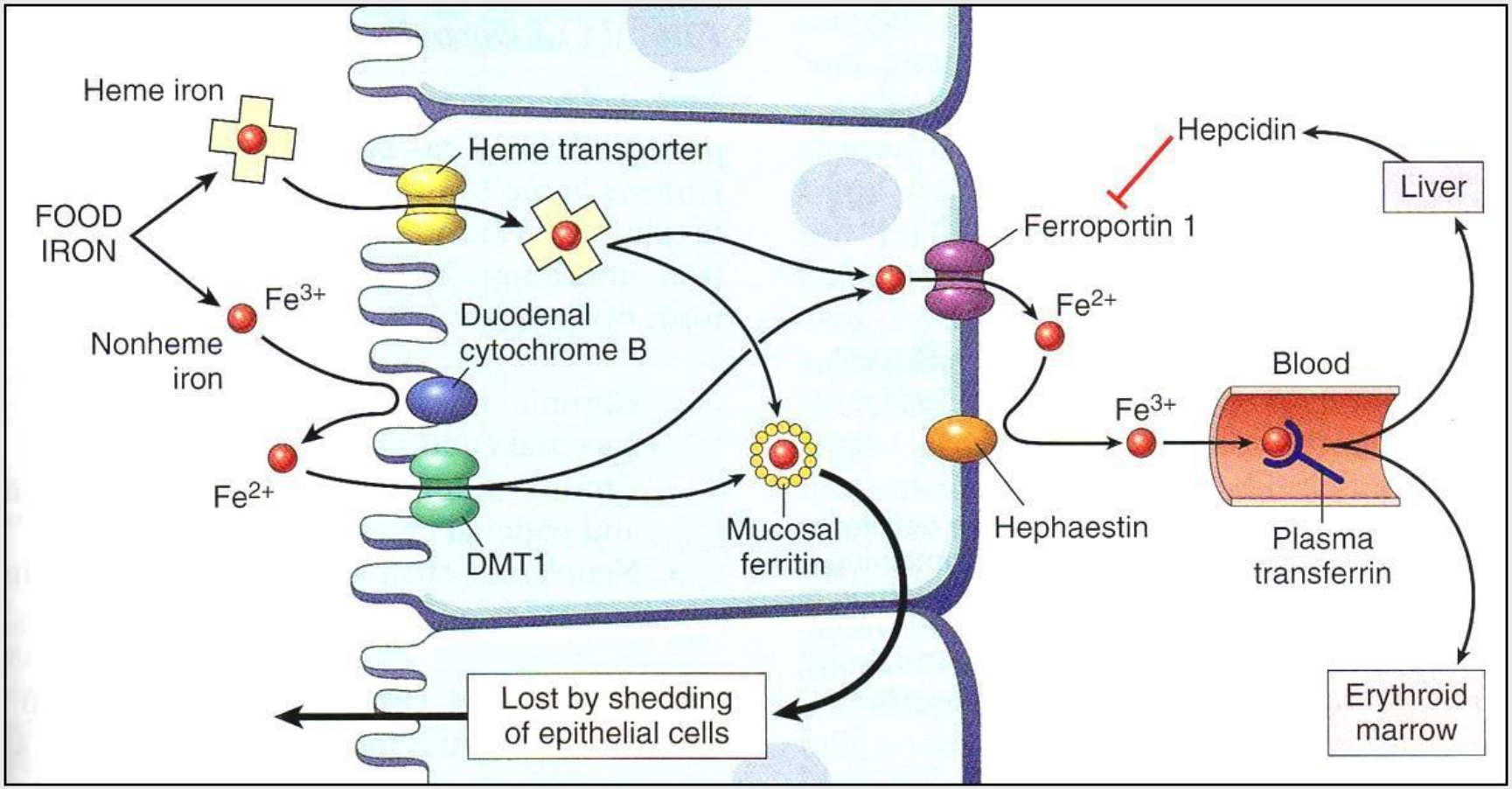
Vitamin B6 (pyridoxine) – metabolism of amino acids, synthesis of hem

Vitamin B2 (riboflavin) – part of flavoprotein enzymes – reductases of erythrocytes (normal function and survival of erythrocytes). Normocyte anaemia with lower reticulocytes count.

Vitamin C (ascorbic acid) – non-specific function in erythropoesis.

Hormonal influences

Androgens, estrogens, hormones of thyroid gland, glucocorticoids, growth hormone.


Heme iron
FOOD IRON
Nonheme iron
Fe3+
Fe2+
Heme transporter
Duodenal cytochrome B
DMT1
Mucosal ferritin
Lost by shedding of epithelial cells
Hepcidin
Liver
Ferroportin 1
Fe2+
Fe3+
Hephaestin
Blood
Plasma transferrin
Erythroid marrow

ANAEMIA

Disorder, in which basic and characteristic feature is **lower amount of haemoglobin.** Usually also haematocrit and red blood cell count in 1 litre of blood are below physiological value.

CLASSIFICATION OF ANEMIAS

MORPHOLOGICAL CLASSIFICATION

Evaluation of erythrocyte volume and concentration of haemoglobin in erythrocytes

1. Normocyte anaemia
2. Microcyte a.
3. Macrocyte

1. Normochromic anaemia
2. Hypochromic a.

PATHOPHYSIOLOGICAL CLASSIFICATION

Anaemias caused by inefficient blood production

Sideropenic anaemias – lack of iron

Megaloblastic a. – lack of vitamin B_{12} or folic acid

Anaemias caused by suppression of blood production

Anaemias in chronic diseases and symptomatic anaemias

Thalasemia

Anaemias caused by increased losses

Haemolytic a.– caused by increased destruction of erythrocytes

Chronic posthaemorhagic anemia

Acute posthaemorhagic anaemia

ANTIGENS AND ANTIBODIES OF RED BLOOD CELLS

1) History of blood transfusions.

2) ***Posttransfusion reactions***: aglutination, haemolysis (immediate or delayed), life-threatening complications (jaundice, damage of kidneys, anuria, death – in case of full blood or RBCs administration, in case of plasma – dilution of aglutinins!!!
Autoimmune diseases. Paternity tests, event. transplantology.

3) ***Antigens of blood cells*:**
a) 30 antigen systems (ABO, Rh, MNSs, Lutheran, Kell, Kidd, Lewis, Diego, P, Duffy…)
b) hundreds of other – „weak" – antigens (important for paternity testing, organ transplantations)

4) ***Aglutinogen*:** antigen of plasmatic membrane of cells
- complex oligosaccharide
- erytrocytes, salivary glands, pancreas, liver, kidney, lungs, testes
- saliva, sperm, amnionic fluid, milk, urine

5) ***Aglutinin:*** antibody against aglutinogen, γ-globulin (IgM –AB0 system, IgG – Rh system), produced in the same way as other antibodies
- **after births almost zero concentration in blood**
- production of aglutinins begins 2-8 months after birth: **stimulation by antigens similar to aglutinogens – in food, in GIT bacteria**
- maximal concentration of antibodies is reached in 8-10 years, decreases gradually with age

Blood group systems

ISBT №[1]	System name	System symbol	Epitope or carrier, notes	Chromosome
001	ABO	ABO	Carbohydrate (N-Acetylgalactosamine, galactose). A, B and H antigens mainly elicit IgM antibody reactions, although anti-H is very rare, see the Hh antigen system (Bombay phenotype, ISBT #18).	9q34.2
002	MNS	MNS	GPA / GPB (glycophorins A and B). Main antigens M, N, S, s.	4q31.21
003	P	P	Glycolipid. Three antigens: P_1, P, and P^k	22q13.2
004	Rh	RH	Protein. C, c, D, E, e antigens (there is no "d" antigen; lowercase "d" indicates the absence of D).	1p36.11
005	Lutheran	LU	Protein (member of the immunoglobulin superfamily). Set of 21 antigens.	19q13.32
006	Kell	KEL	Glycoprotein. K_1 can cause hemolytic disease of the newborn (anti-Kell), which can be severe.	7q34
007	Lewis	LE	Carbohydrate (fucose residue). Main antigens Le^a and Le^b — associated with tissue ABH antigen secretion.	19p13.3
008	Duffy	FY	Protein (chemokine receptor). Main antigens Fy^a and Fy^b. Individuals lacking Duffy antigens altogether are immune to malaria caused by *Plasmodium vivax* and *Plasmodium knowlesi*.	1q23.2
009	Kidd	JK	Protein (urea transporter). Main antigens Jk^a and Jk^b.	18q12.3
010	Diego	DI	Glycoprotein (band 3, AE 1, or anion exchange). Positive blood is found only among East Asians and Native Americans.	17q21.31
011	Yt	YT	Protein (AChE, acetylcholinesterase).	7q22.1
012	XG	XG	Glycoprotein.	Xp22.33
013	Scianna	SC	Glycoprotein.	1p34.2
014	Dombrock	DO	Glycoprotein (fixed to cell membrane by GPI, or glycosyl-phosphatidyl-inositol).	12p12.3
015	Colton	CO	Aquaporin 1. Main antigens Co(a) and Co(b).	7p14.3
016	Landsteiner-Wiener	LW	Protein (member of the immunoglobulin superfamily).	19p13.2
017	Chido	CH	C4A C4B (complement fractions).	6p21.3
018	Hh	H	Carbohydrate (fucose residue).	19q13.33
019	XK	XK	Glycoprotein.	Xp21.1
020	Gerbich	GE	GPC / GPD (Glycophorins C and D).	2q14.3
021	Cromer	CROM	Glycoprotein (DAF or CD55, regulates complement fractions C3 and C5, attached to the membrane by GPI).	1q32.2
022	Knops	KN	Glycoprotein (CR1 or CD35, immune complex receptor).	1q32.2
023	Indian	IN	Glycoprotein (CD44 adhesion function?).	11p13
024	Ok	OK	Glycoprotein (CD147).	19p13.3
025	Raph	RAPH	Transmembrane glycoprotein.	11p15.5
026	JMH	JMH	Protein (fixed to cell membrane by GPI). Also known as Semaphorin 7A or CD108.	15q24.1
027	Ii	I	Branched (I) / unbranched (i) polysaccharide.	6p24.2
028	Globoside	GLOB	Glycolipid. Antigen P.	3q26.1
029	GIL	GIL	Aquaporin 3.	9p13.3
030	Rh-associated glycoprotein	RHAg	Rh-associated glycoprotein.	6p21-qter
031	Forssman	FORS	Globoside alpha-1,3-N-acetylgalactosaminyltransferase 1 (GBGT1)	9q34.13
032	Langereis[4]	LAN	ABCB6. Porphyrin transporter	2q36
033	Junior[4]	JR	ABCG2. Multi-drug transporter protein	4q22
034	Vel	Vel	Human red cell antigens	1p36.32
035	CD59	CD59		11p13

A-B-O SYSTEM

Genotype	Blood group	Aglutinogen	Aglutinin
00	0	(H)	anti-A a anti-B
0A or AA	A	A	anti-B
0B or BB	B	B	anti-A
AB	AB	A and B	-

Described by Landsteiner in 1901, 1930 – awarded by Nobel Price.
Janský -1906.

Frequency of blood groups in ABO system:

O	47% (38%)
A	41% (42%)
B	9% (14%)
AB	3% (6,5%)

Subgroups in A a B blood groups.
A_1 (1 million copies of antigen on 1 ery), A_2 (250 thousands copies).

Heredity: both A and B is inherited dominantly, according to Mendel´s law.

Rh SYSTEM

Monkey *Maccacus rhesus*.
40th of the 20th century, Wiener a Landsteiner.
Frequency: 85% - Rh^+, 15% - Rh^-.

Antigens D, C, E, d, c, e. Present only on erythrocytes.

D – the „strongest“ antigen: Rh – positive, Rh – negative (produces anti-D aglutinin after contact with D-erythrocytes).

Aglutinins production: only after the contact with D-erythrocytes (transfusion, foetal erythroblastosis).
High concentration of anti-D antibodies lasts for many years!!!

HAEMOLYTIC JAUNDICE OF NEWBORNS

Rh-negative mother x Rh-positive foetus.

First pregnancy – immunisation of mother during delivery (or interruption or miscarriage!!!).

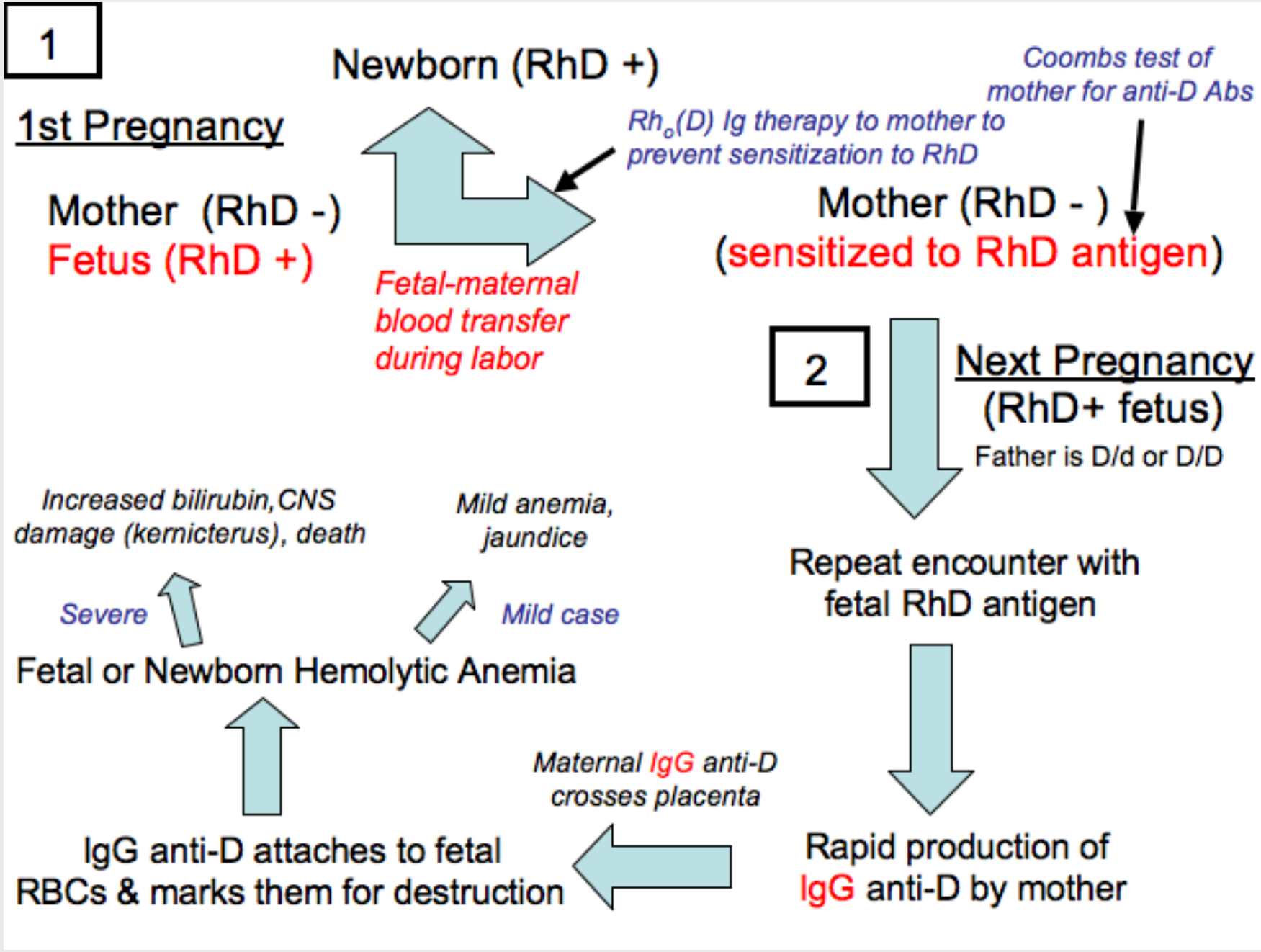
Next pregnancy – anti-D aglutinins (IgG) cross foetoplacental barrier.

Foetus damage: approx. in 17% of next pregnancies

Haemolysis of foetal erythrocytes – haemolyti disease of newborn (erythroblastosis fetalis):
•anaemia
•jaundice
•oedemas – event. hydrops fetalis
•CNS damage (icterus) –bile acids enter CNS (no haematoencephalic barrier!)
•deaths of foetus in utero

***Prevention of foetal damage*:**
1) administration of small doses of anti-D antibodies to mother during pregnancy
2) administration of one dose of anti-D antibodies during postpartum period

Success of therapy: up 90%.


1
Newborn (RhD +)
1st Pregnancy
Mother (RhD -)
Fetus (RhD +)
Fetal-maternal blood transfer during labor
Rh$_o$(D) Ig therapy to mother to prevent sensitization to RhD
Coombs test of mother for anti-D Abs
Mother (RhD -)
(sensitized to RhD antigen)
2
Next Pregnancy
(RhD+ fetus)
Father is D/d or D/D
Repeat encounter with fetal RhD antigen
Rapid production of IgG anti-D by mother
Maternal IgG anti-D crosses placenta
IgG anti-D attaches to fetal RBCs & marks them for destruction
Fetal or Newborn Hemolytic Anemia
Severe
Increased bilirubin, CNS damage (kernicterus), death
Mild case
Mild anemia, jaundice