Blood coagulation

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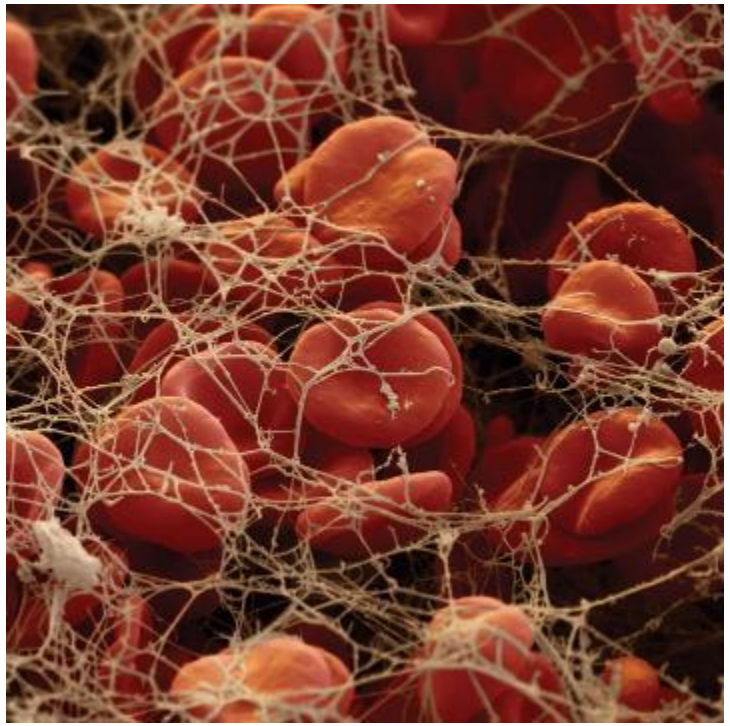
Hematopoietic-lymphatic system

What is blood coagulation (clotting)?

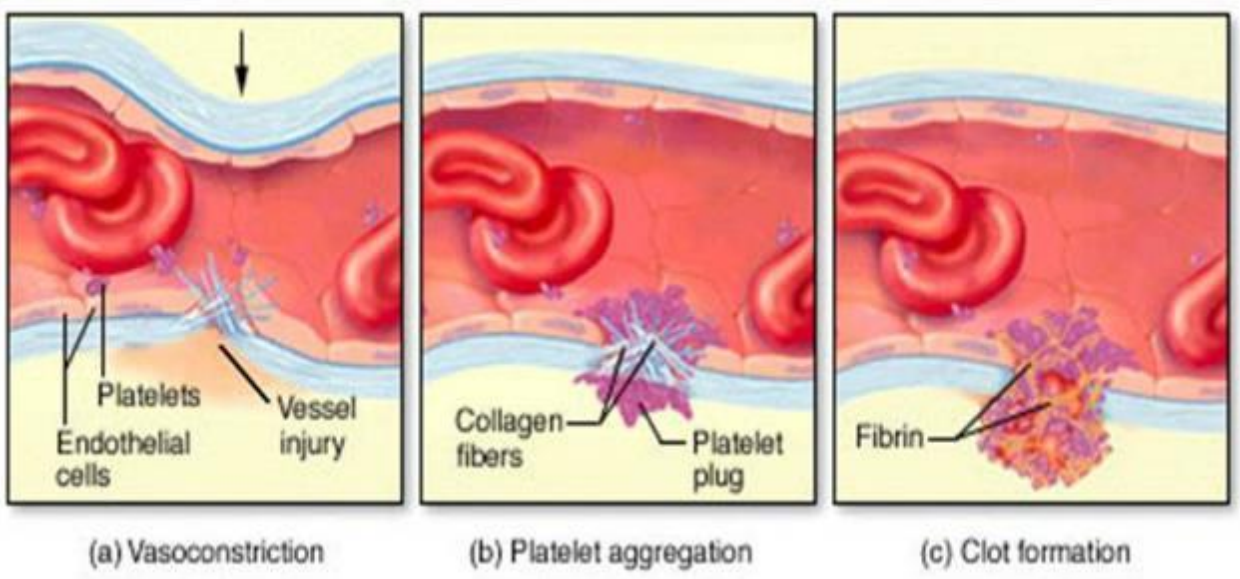
- It is an *orchestrated*, biochemical process that is initiated as a result of vascular injury where a small area blood of surrounding injury changes from liquid to gel, forming a clot made of fibrin, which results in hemostasis (the cessation of blood loss) followed by clot dissolution and repair.



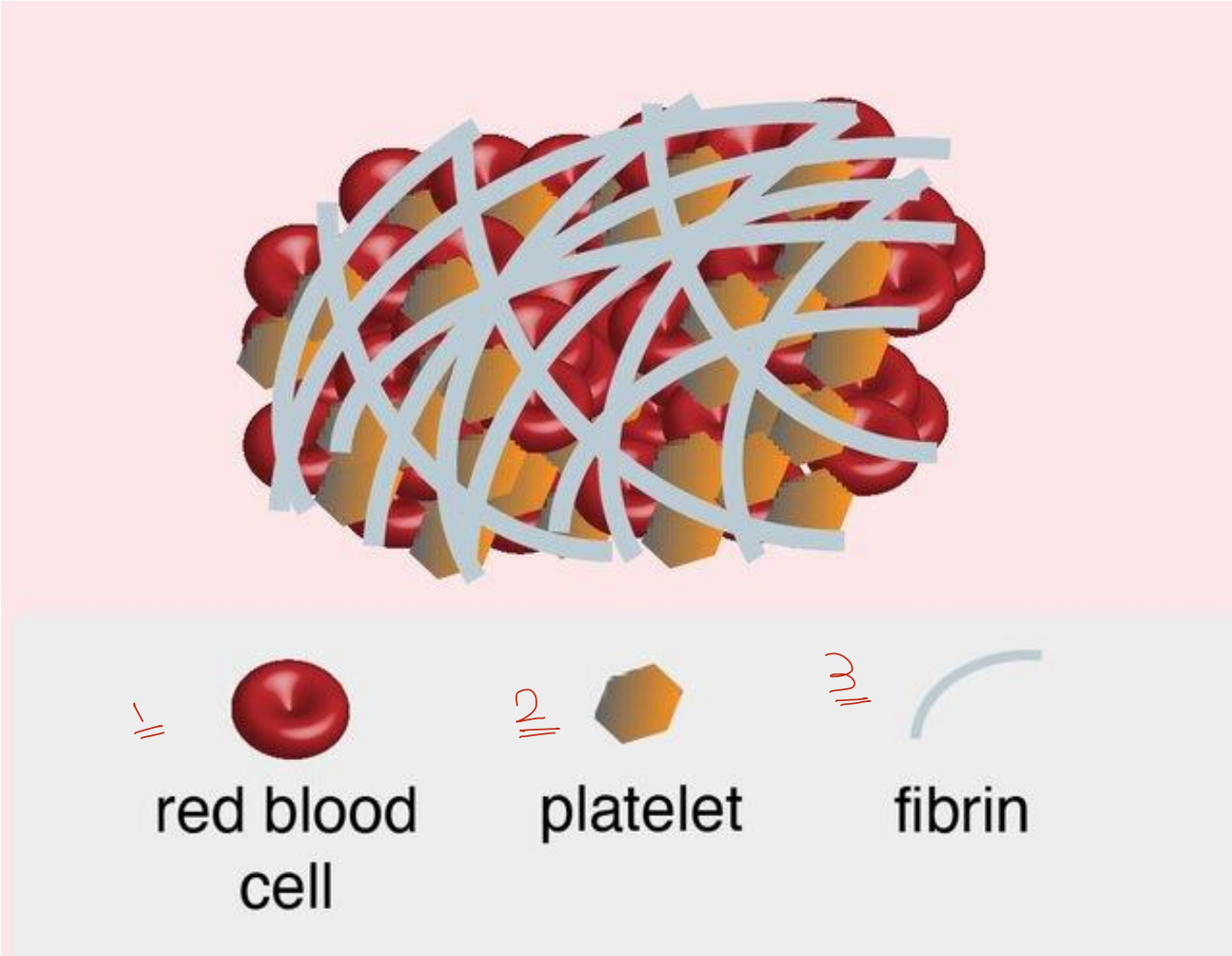
Steps of hemostasis and thrombosis

- Vascular constriction limiting blood flow to the area of injury
- Activation then aggregation of platelets at the site of injury, forming a loose platelet plug
- Formation of a fibrin mesh to entrap the plug
- Dissolution of the clot in order for normal blood flow to resume following tissue repair

remove



Composition of a clot → main components

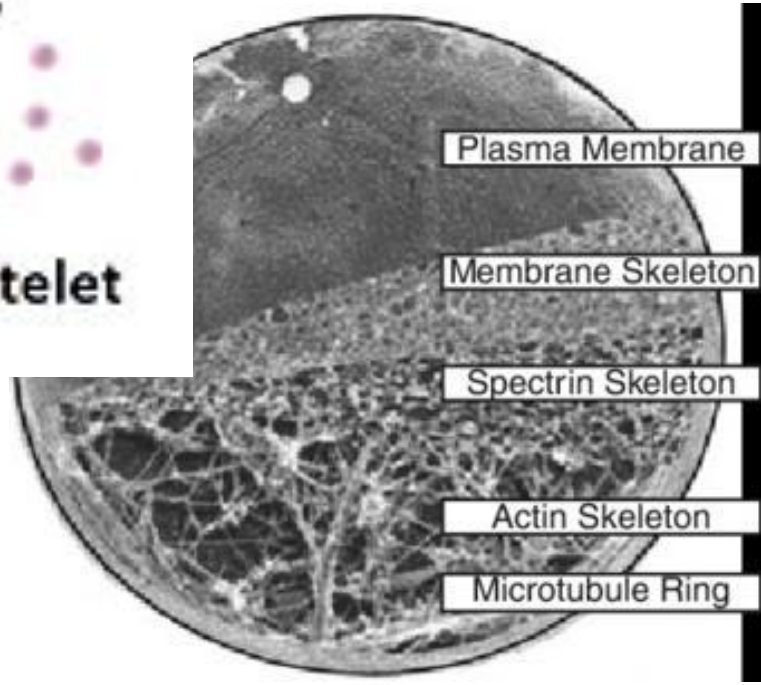


Platelets are a major player

- Small anuclear cell fragments produced from the megakaryocytes.
- Platelets have numerous kinds of surface receptors.
- Platelets also have actin filaments and myosin, which change the shape of the platelet upon activation. → allow more Platelet for aggregation
- They also have three types of granules that store substances that are released upon platelet activation.

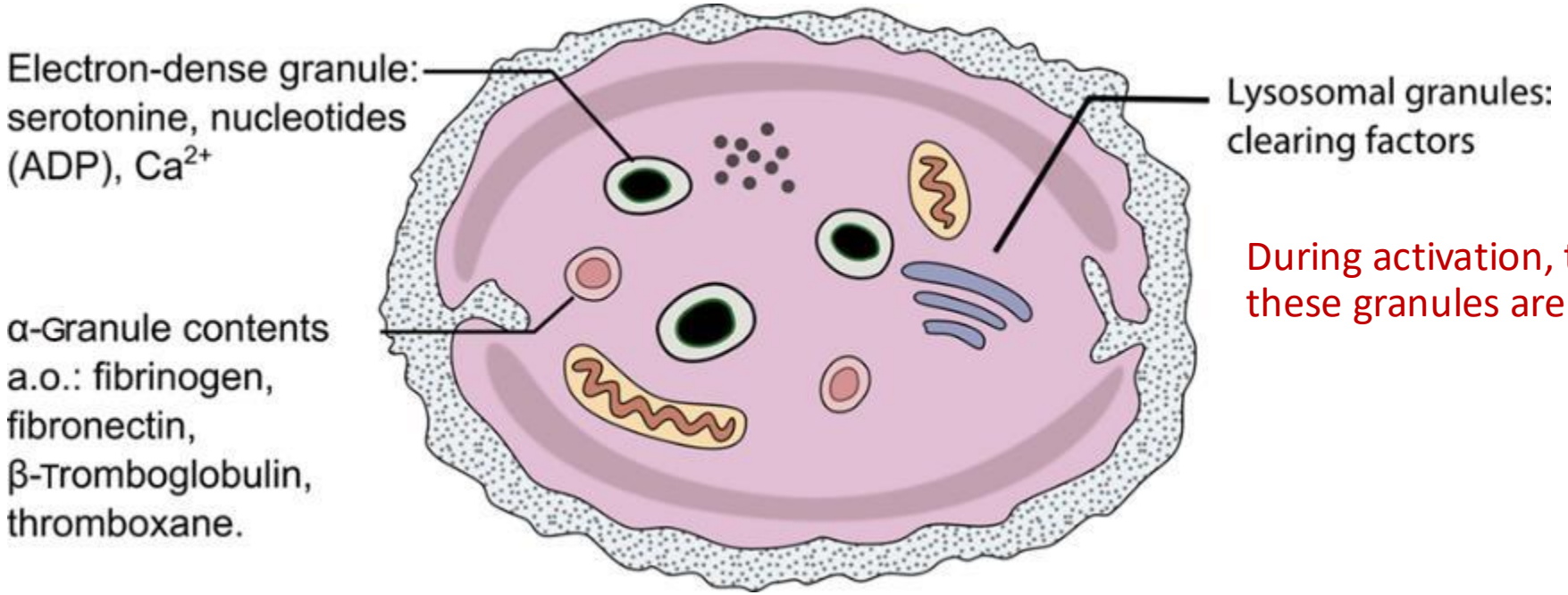
Megakaryocyte

Platelet

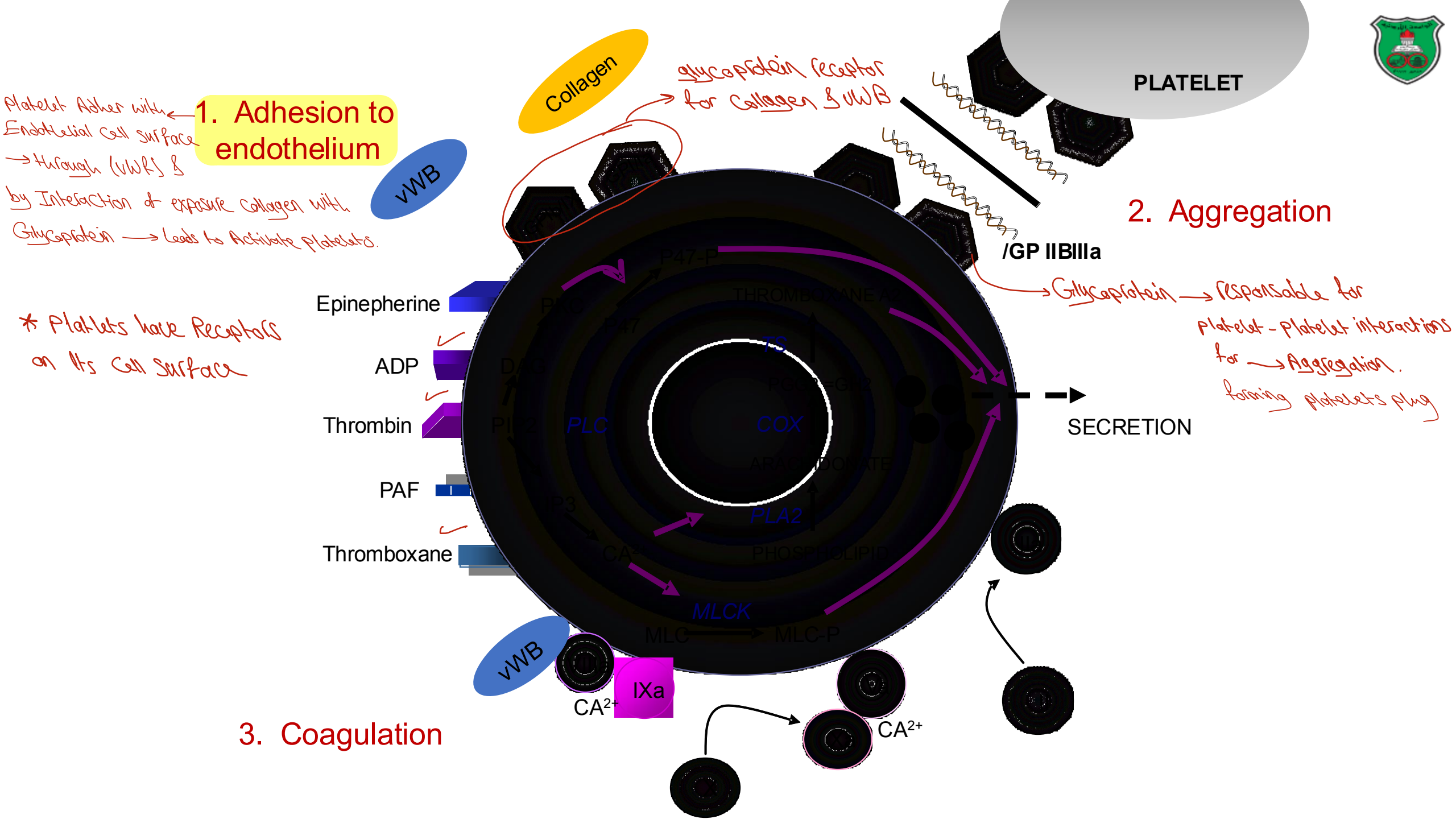


The granules

- Electron-dense granules (calcium ions, ADP, ATP, serotonin)
- α-granule (a heparin antagonist, platelet-derived growth factor, fibrinogen, von Willebrand factor (vWF), clotting factors)
- Lysosomal granules (hydrolytic enzymes)



During activation, the contents of these granules are secreted.

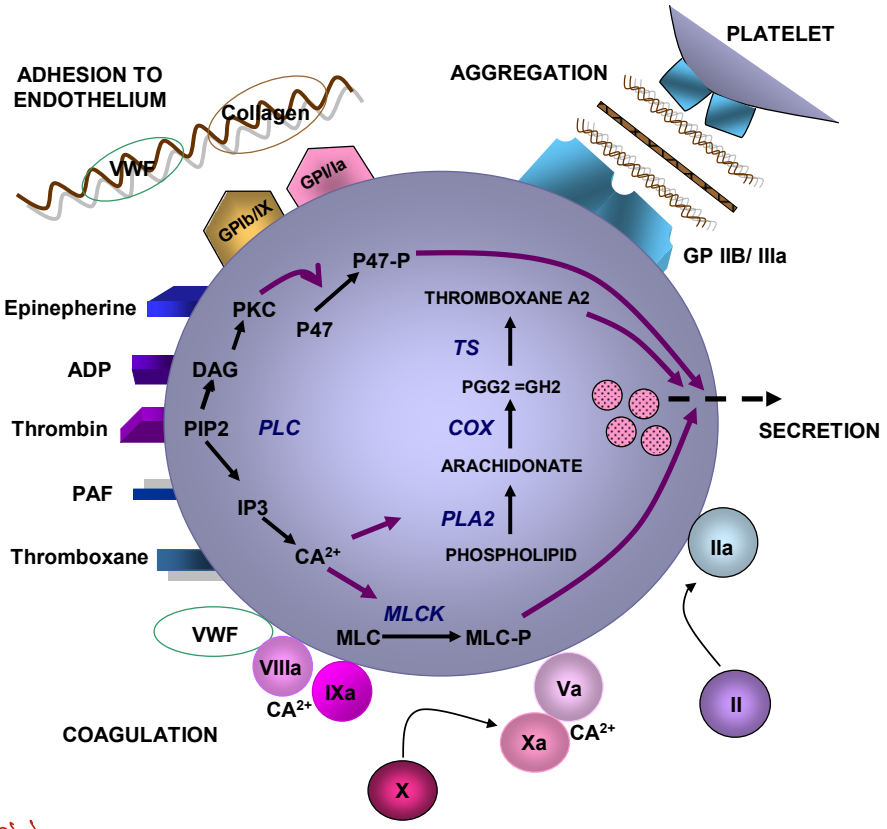

1. Adhesion to endothelium
Platelet Adher with Endothelial cell surface → through (vWF) & by Interaction & exposure collagen with Glycoprotein → Leads to Activate Platelets.
Collagen
vWB
glycoprotein receptor for Collagen & vWB
PLATELET
/GP IIBIIIa
2. Aggregation
Glycoprotein → responsable for platelet - platelet interactions for → Aggregation. forming platelets plug
* Platlets have Receptors on its cell surface
Epinepherine
ADP
Thrombin
PAF
Thromboxane
P47-P
THROMBOXANE A2
TS
PLC
COX
PLA2
PHOSPHOLIPID
MLCK
MLC
MLC-P
vWB
IXa
CA2+
CA2+
3. Coagulation

Injury → exposure Collagen → Presence (vWF) on surface of Endothelial cells → Interaction Platelets with Collagen & vWF → Platelets Release granules → Endothelial proteins & also found in Platelets

Adhesion

- The endothelial von Willebrand factor (vWF) protein and exposed collagen bind to the platelet glycoproteins (GP).
- Some platelets release substances from the granules:
  - ADP
  - Serotonin
  - Factor V
  - ATP
  - Calcium
  - Fibrinogen
  - vWF
  - Thrombin
  - Thromoxane

Bind to receptors



Resting Platelet Non-Active → Active → Aggregat Platelets (Platelet Plug)

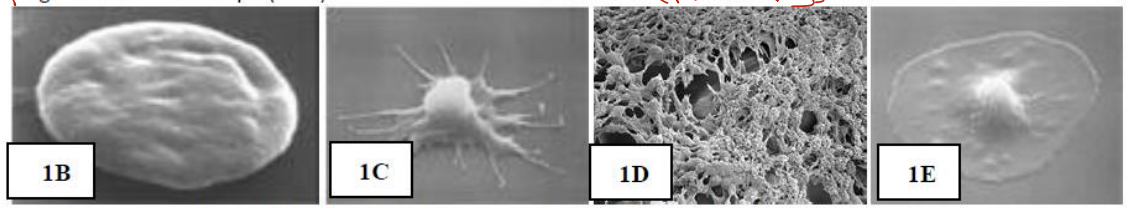
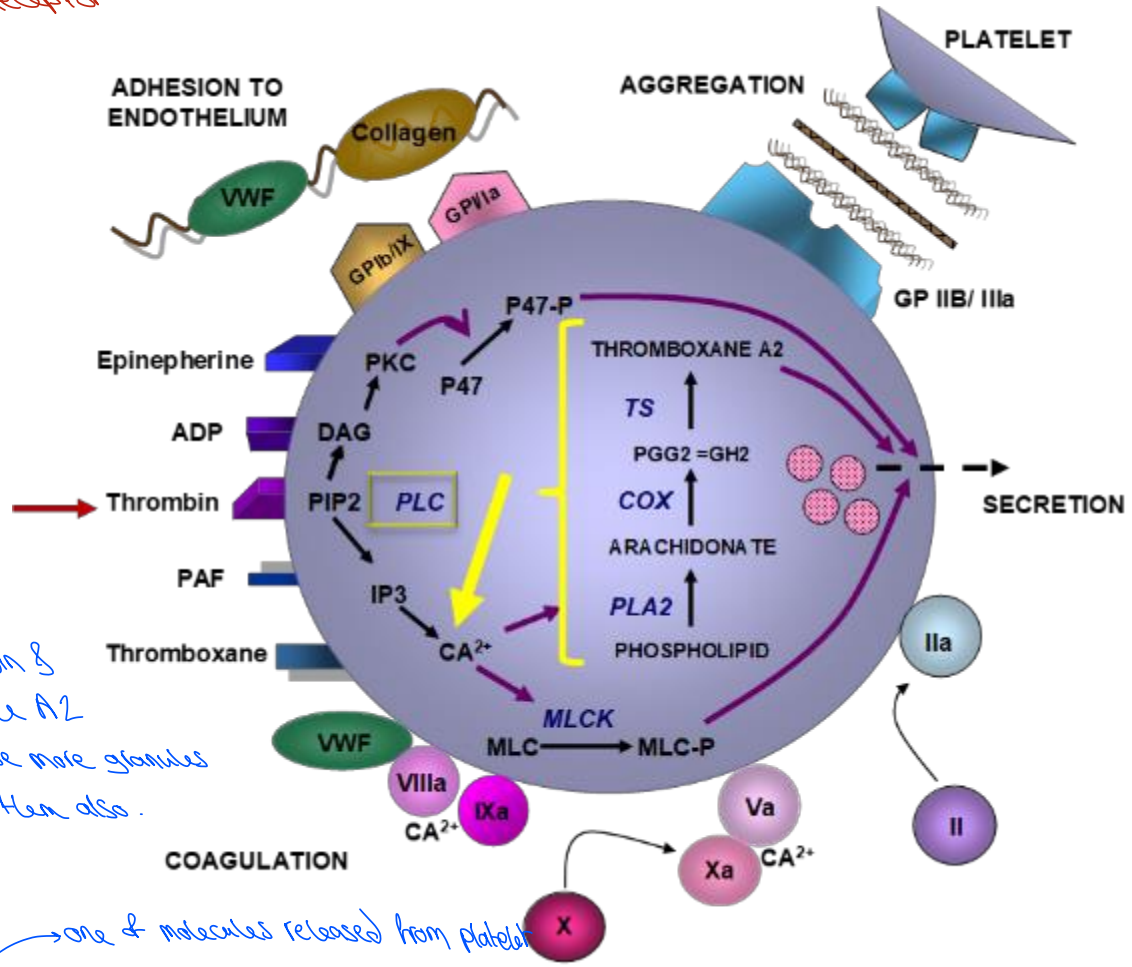


Figure 1 [(**B**) Platelet in resting mode (**C**) Activated platelets change into a pseudopodia shape (**D**) Aggregated platelets (**E**) Platelet spreading]

- Platelets also change their shape allowing for more platelet-platelet interaction and aggregation.

Thrombin receptor

- Thrombin receptor activates a G protein that activates phospholipase C-β (PLC-β).
- PLC-β hydrolyzes phosphatidylinositol-4,5-bisphosphate (PIP2) into inositol trisphosphate (IP3) and diacylglycerol (DAG).
- IP3 induces the release of intracellular Ca^{2+} stores, and DAG activates protein kinase C (PKC).
- Ca^{2+} triggers the release of arachidonate from membrane phospholipids by phospholipase A2.
- Arachidonate is converted by cyclooxygenase to prostaglandins, which are then converted by thromboxane synthetase to thromboxane A2.
  - Thromboxane is as vasoconstrictor and a further inducer of PLC-β activity (and platelet aggregation).
  - It acts in autocrine and paracrine manners.



- Serotonin is also a vasoconstrictor.
- PDGF stimulates proliferation of endothelial cells to reduce blood flow.

Cox-1 responsable for → Activation for PG & Thromboxan A2 → platelets formation.

Aspirin ⊖

NSAID

- Non-steroidal anti-inflammatory drugs inhibit the cyclooxygenase, accounting for their anticoagulant effects.
  - Aspirin also inhibits production of endothelial prostacyclin, which opposes platelet aggregation and is a vasodilator, but, unlike platelets, these endothelial cells regenerate cyclooxygenase within a few hours. Thus, the overall balance between TxA2 and PGI2 can be shifted in favor of the latter.

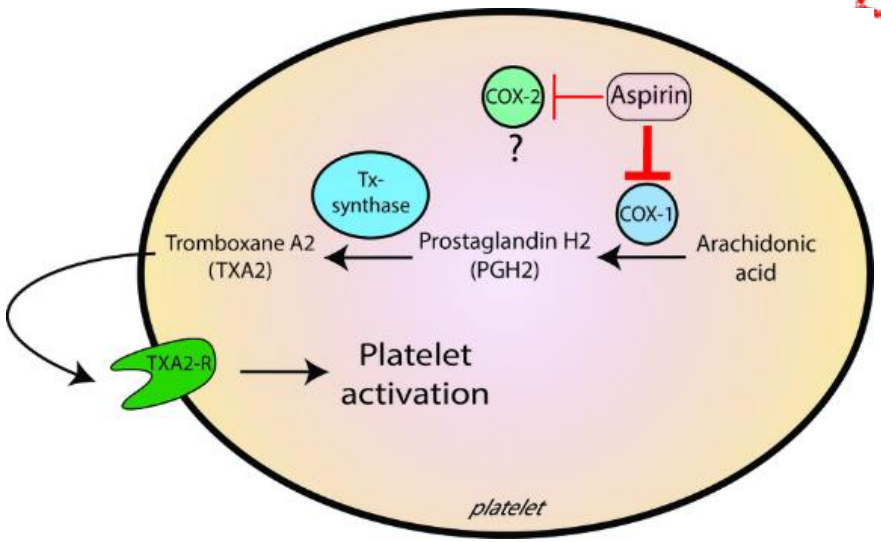
Inflammatory ↓ Effects & Thr

Inhibition ↑

Anti-Coagulant But have Risk of Causing Excisive Bleeding in Aldelay (↑ age) (Dose dependant).

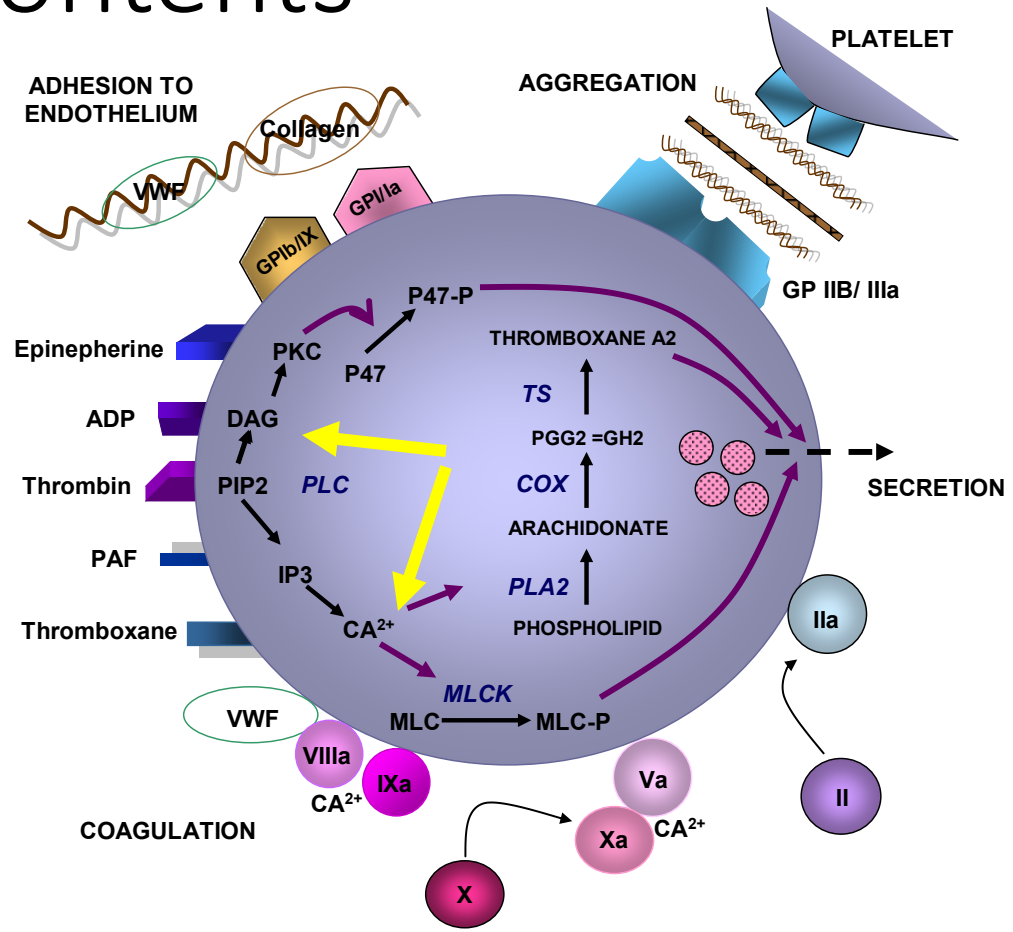
But → initial action is by → inflammatory molecule: PG TxA2 Then at end → Prostacyclin

WARNING



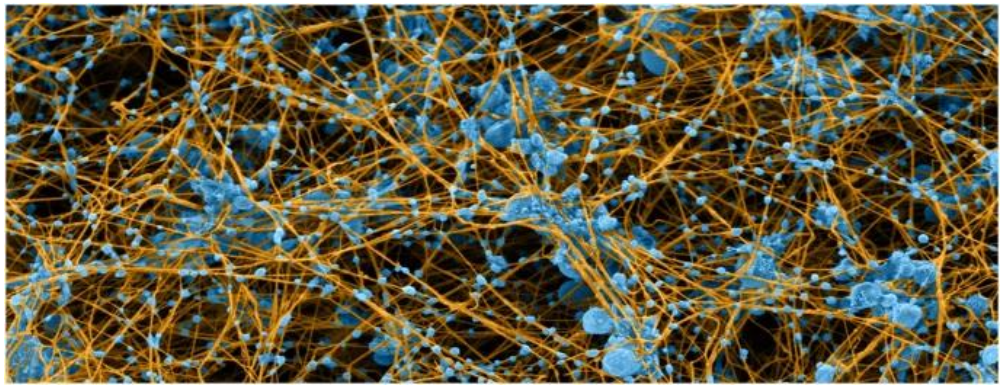
More release of granular contents

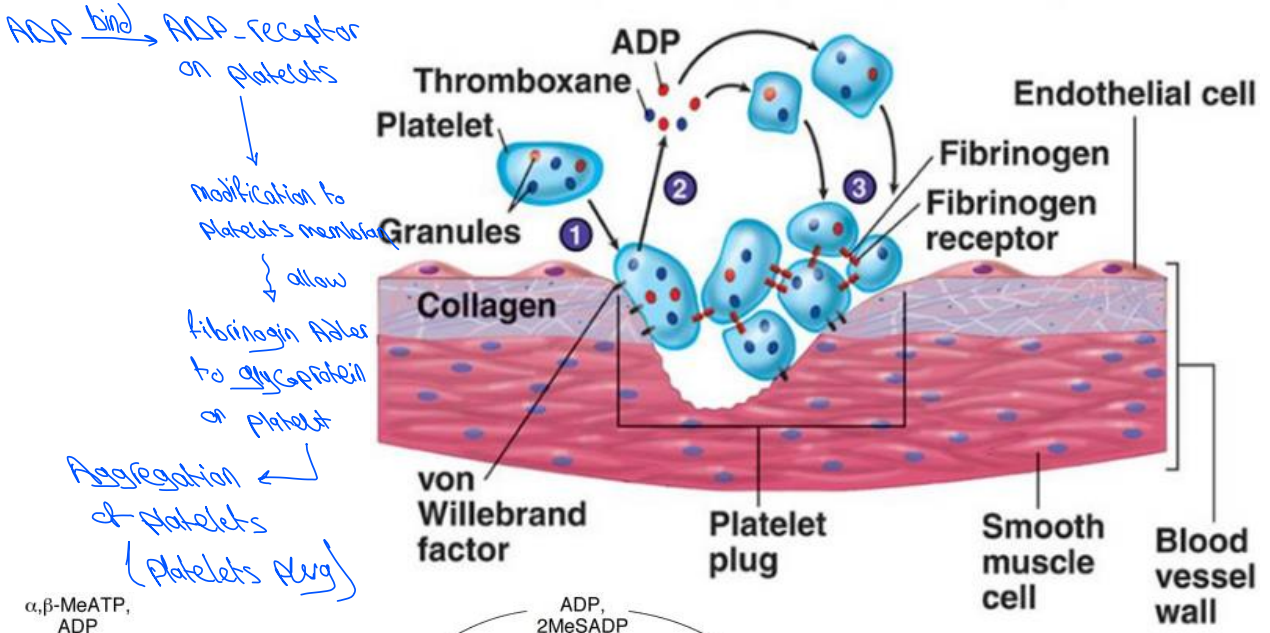
- Ca^{2+} activates myosin light chain kinase (MLCK), which
- phosphorylates the light chain of myosin allowing it to interact with actin and resulting in altered platelet morphology, induced motility, and release of granules.
- DAG activates PKC, which phosphorylates and activates specific platelet proteins that induce the release of platelet granule contents including ADP.

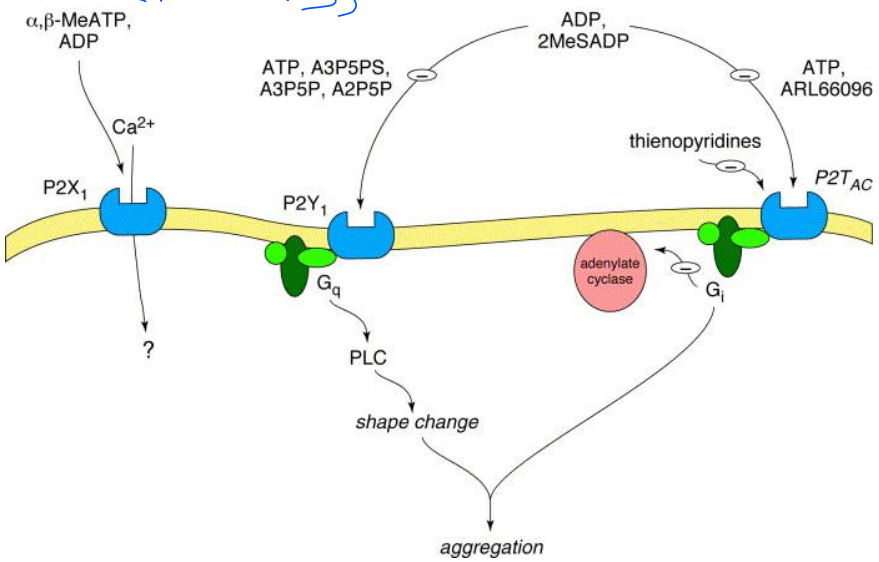


ADP drives the formation of platelet plug

- ADP is a platelet activator that binds to its receptor and modifies the platelet membrane allowing fibrinogen to adhere to platelet surface glycoproteins resulting in fibrinogen-induced platelet aggregation, called platelet plug.

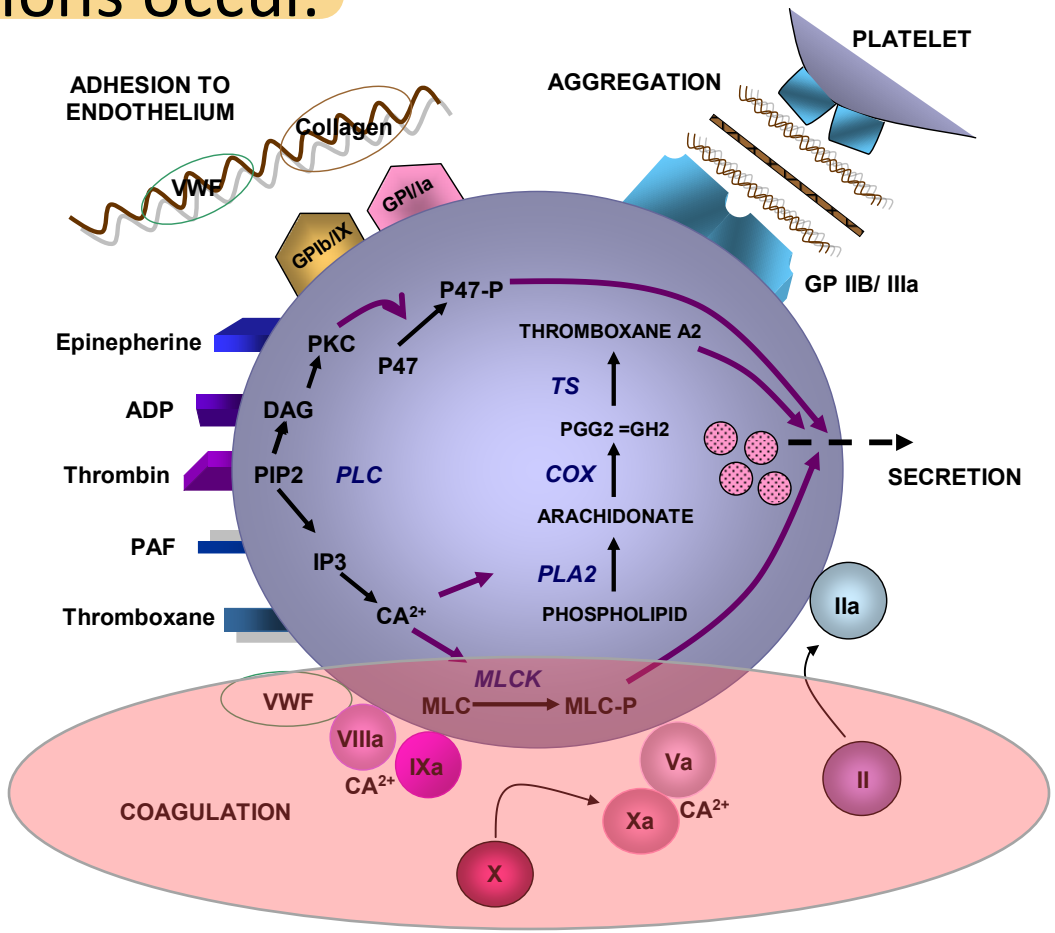






Role of platelet cell surface → Coagulation on surface of Endothelial cells.

- The accumulated platelet plug provides an important surface on which coagulation reactions occur.



Biochemistry of coagulation

Components of coagulation

- An organizing surface (platelets) Plug
- Proteolytic zymogens (prekallikrein, prothrombin, and factors VII, IX, X, XI, XII, and XIII) → inactive enzyme needs proteolytic cleavage for Activation
  - These are mainly serine proproteases released from hepatocytes.
  - The subscript "a" designates the activated form of a factor
    - e.g., “XIII" is versus "XIIIa"
- Anti-coagulants (protein C, protein S)
- Non-enzymatic protein cofactors (factors VIII, V, and tissue factor) → not Enzyme
- Calcium ions
- Vitamin K
- Fibrinogen

Table 3: illustrates the engagement and detailed explanation of coagulation factors, that aid in the blood coagulation cascade

Factor	Name	Source	Pathway	Description	Function
I	Fib	Liver	Common	Plasma glycoprotein; Molecular Weight (MW)= 340 kilodaltons (kDa)	Adhesive protein which aids in fibrin clot formation.
II	Prothrombin	Liver	Common	Vitamin K-dependent serine protease; MW= 72 kDa	Presence in the activated form and the main enzyme of coagulation
III	Tissue factor	Secrete by the damaged cells and platelets	Extrinsic and Intrinsic	Known as thromboplastin; MW= 37 kDa	Lipoprotein initiator of the extrinsic pathway
IV	Calcium ions	Bone and gut	Entire process	Required for coagulation factors to bind to phospholipid (formerly known as factor IV)	Metal cation which is important in coagulation mechanisms
V	Proaccererin / Labile factor	Liver and platelets	Intrinsic and extrinsic	MW = 330 kDa	Cofactor for the activation of prothrombin to thrombin (prothrombinase complex)
VII	Proconvertin (stable factor)	Liver	Extrinsic	MW = 50 kDa; vitamin K-dependent serine protease	With tissue factor, initiates extrinsic pathway (Factor IX and X)
VIII	Antihemophilic factor A (cofactor)	Platelets and endothelium	Intrinsic	MW = 330 kDa	Cofactor for intrinsic activation of factor X (which it forms tenase complex)
IX	Christmas factor / Antihemophilic factor B (plasma thromboplastin component)	Liver	Intrinsic	MW = 50 kDa; vitamin K-dependent serine protease	Activated form is enzyme for intrinsic activation of factor X (forms tenase complex with factorVIII)
X	Stuart-Prower factor (enzyme)	Liver	Intrinsic and extrinsic	MW = 58.9 kDa; vitamin K-dependent serine protease	Activated form is the enzyme for final the common pathway activation of prothrombin (forms prothrombinase complex with factor V)
XI	Plasma thromboplastin antecedent	Liver	Intrinsic	MW = 160 kDa; serine protease	Activates intrinsic activator of factor IX
XII	Hageman factor	Liver	Intrinsic; (activates plasmin)	MW = 80 kDa; serine protease	Initiates activated partial thromboplastin time (aPTT) based intrinsic pathway; Activates factor XI, VII and prekallikrein
XIII	Fibrin stabilizing factor	Liver	Retards fibrinolysis	MW = 320 kDa; Crosslinks fibrin	Transamidase which cross-links fibrin clot

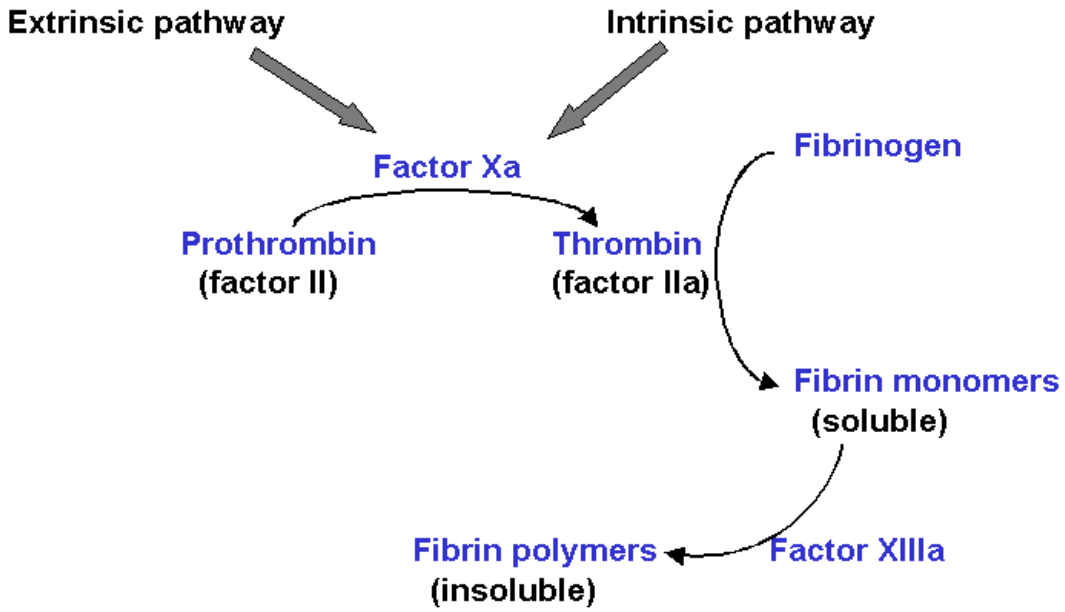
Molecular components of coagulation

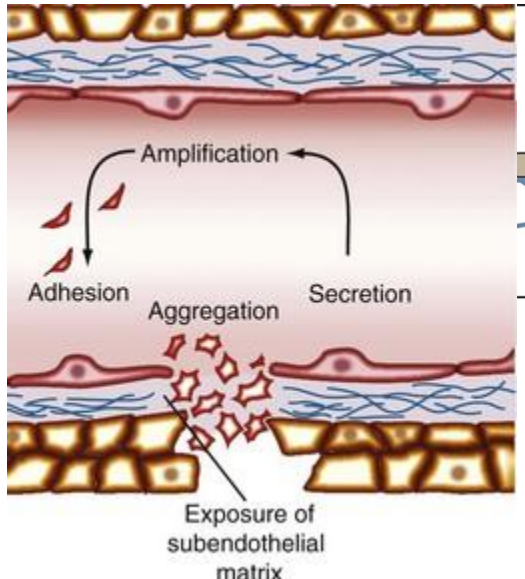
Notes:

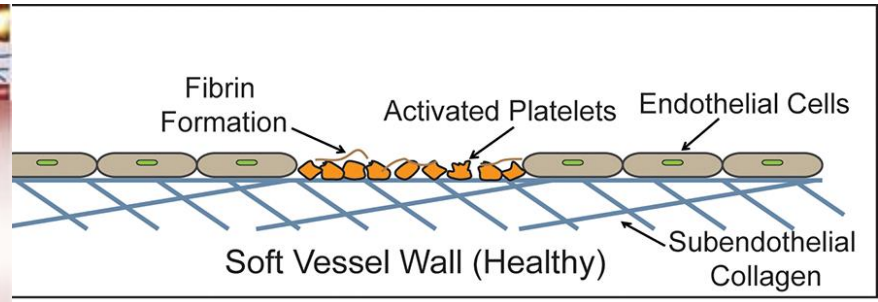
1. Names and symbols
2. Pathway
3. Sources
4. Functions
5. Do not worry about MW

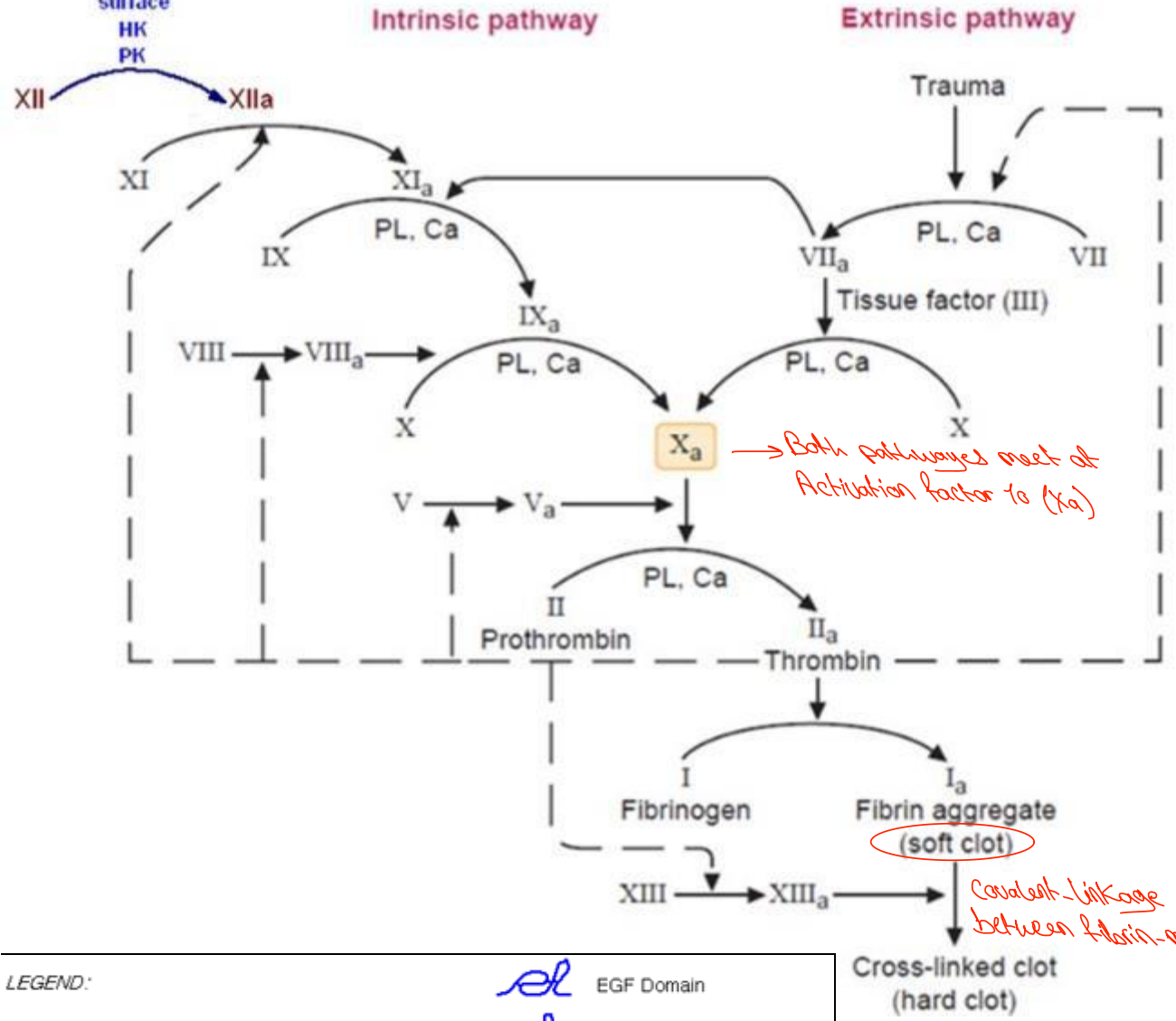
The two pathways

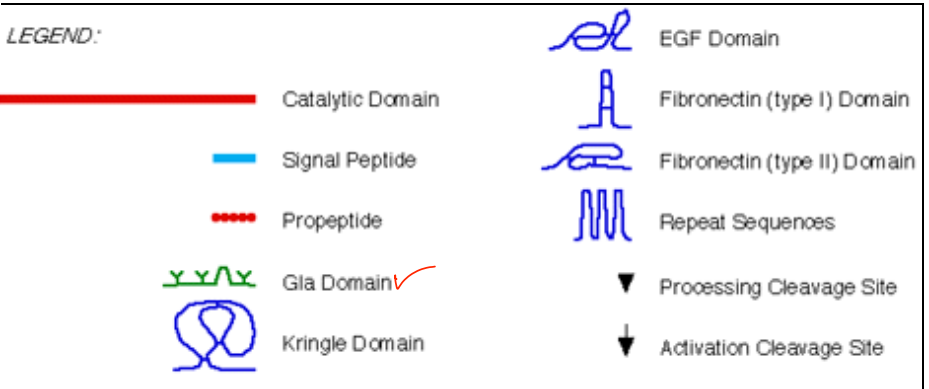
- The intrinsic pathway is initiated when subendothelial surface (i.e., collagen) is exposed.
- The extrinsic pathway is initiated in response to tissue injury.
  - Tissue factor (TF) protein is released.
- However, the two pathways converge on a common pathway.

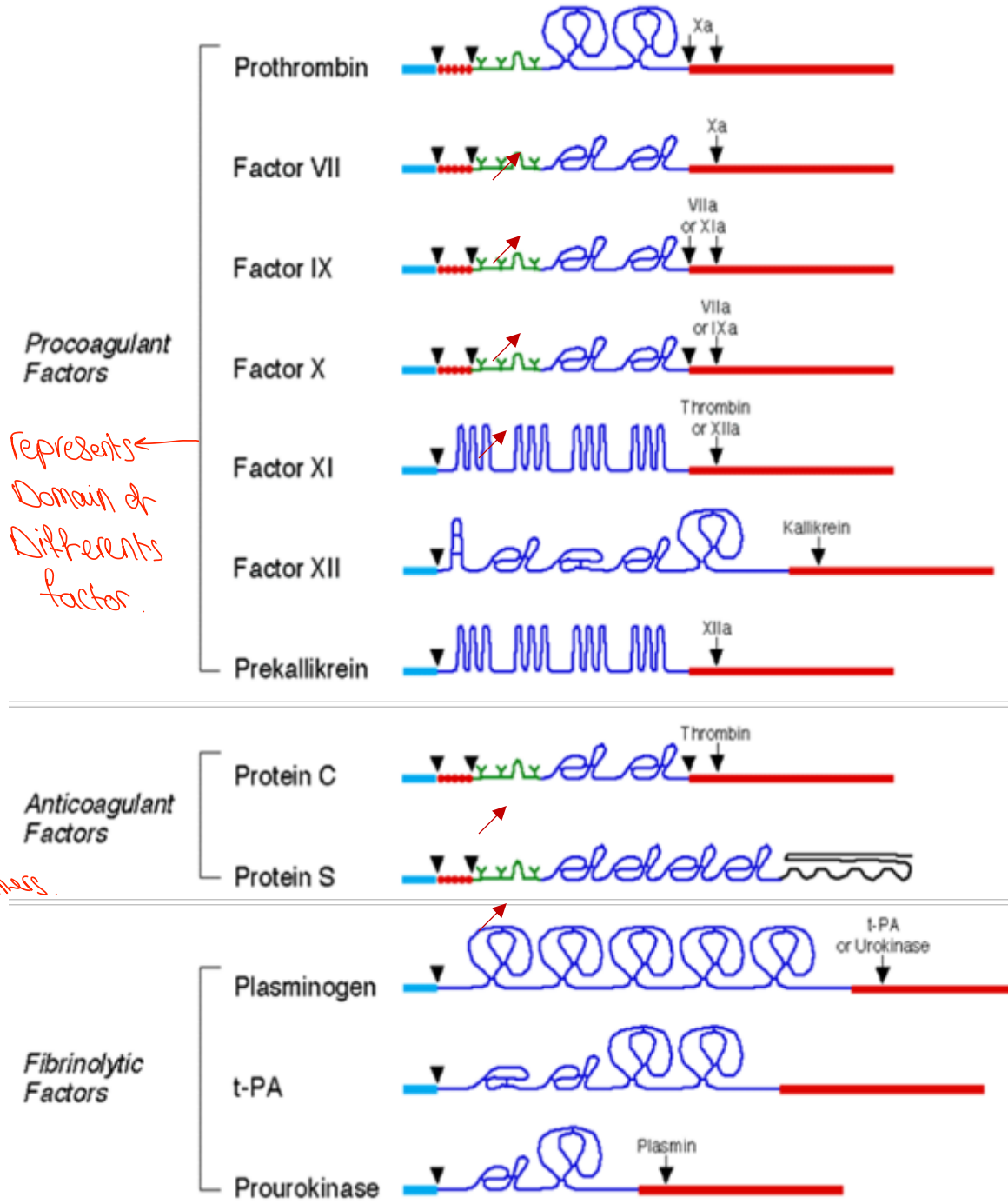







Intrinsic pathway
Extrinsic pathway
surface
HK
PK
XII
XIIa
XI
XIa
IX
PL, Ca
VIIa
PL, Ca
VII
Trauma
Tissue factor (III)
IXa
VIII
VIIIa
PL, Ca
PL, Ca
X
X
Xa
Both pathways meet at Activation factor to (Xa)
V
Va
PL, Ca
II
Prothrombin
IIa
Thrombin
I
Fibrinogen
Ia
Fibrin aggregate
(soft clot)
XIII
XIIIa
Covalent linkage between fibrin monomers
Cross-linked clot
(hard clot)


LEGEND:
Catalytic Domain
Signal Peptide
Propeptide
Gla Domain
Kringle Domain
EGF Domain
Fibronectin (type I) Domain
Fibronectin (type II) Domain
Repeat Sequences
Processing Cleavage Site
Activation Cleavage Site


Procoagulant Factors
Represents Domain of Different factor
Prothrombin
Xa
Factor VII
Xa
Factor IX
VIIa or XIa
Factor X
VIIa or IXa
Factor XI
Thrombin or XIIa
Factor XII
Kallikrein
Prekallikrein
XIIa
Anticoagulant Factors
Protein C
Thrombin
Protein S
Fibrinolytic Factors
Plasminogen
t-PA or Urokinase
t-PA
Prourokinase
Plasmin

→ one of sequence of AA inside proteins (factor)

Gla domain

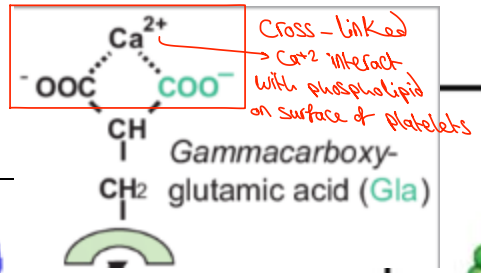
- An ER/Golgi carboxylase binds to prothrombin and factors IX, VII, and X and converts 10≥ glutamate (Glu) residues to γ-carboxyglutamate (Gla), followed by a small (10 a.a.) hydrophobic region.

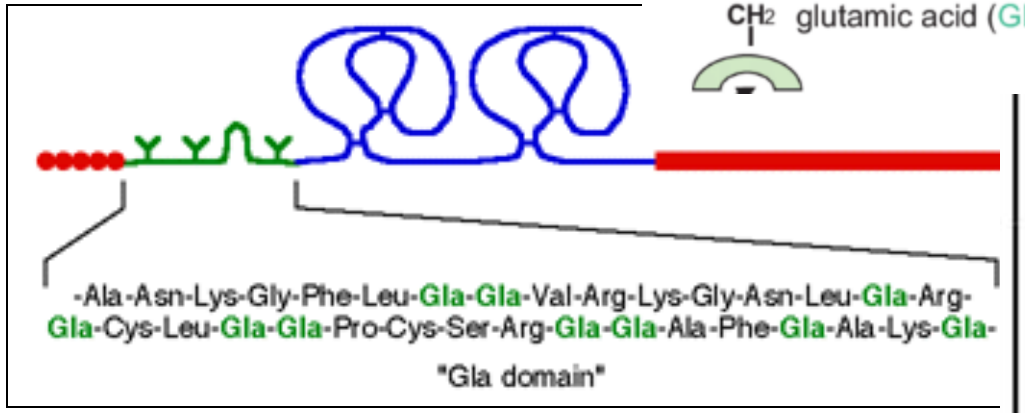
  9 7 10

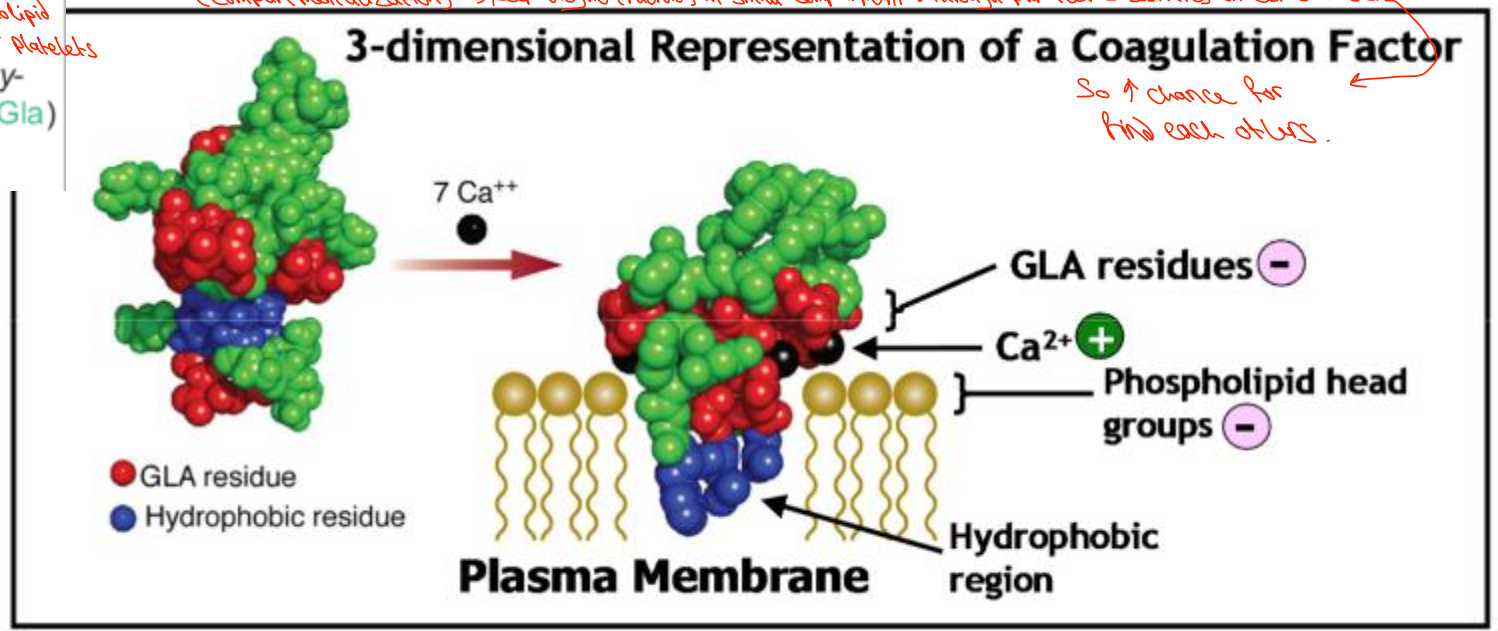
  → Importance is: when Ca^{2+} that released from platelets → to cross-linked

- The Gla residues bind calcium ions and are necessary for the activity of these coagulation factors and formation of a coordinated complex with the charged platelet surface to localize the complex assembly and thrombin formation to the platelet surface.

* Phospholipides (-Vly charge) & Ca^{2+} (+Vly) leads interaction of proteins (have Gla) with phospholipids mediated By Ca^{2+} → aim is to keep all coagulating factors together as well as activation for each other. process called (Compartmentalization) → keep enzyme (factors) in small compartment. through out their substrates on cell surface.

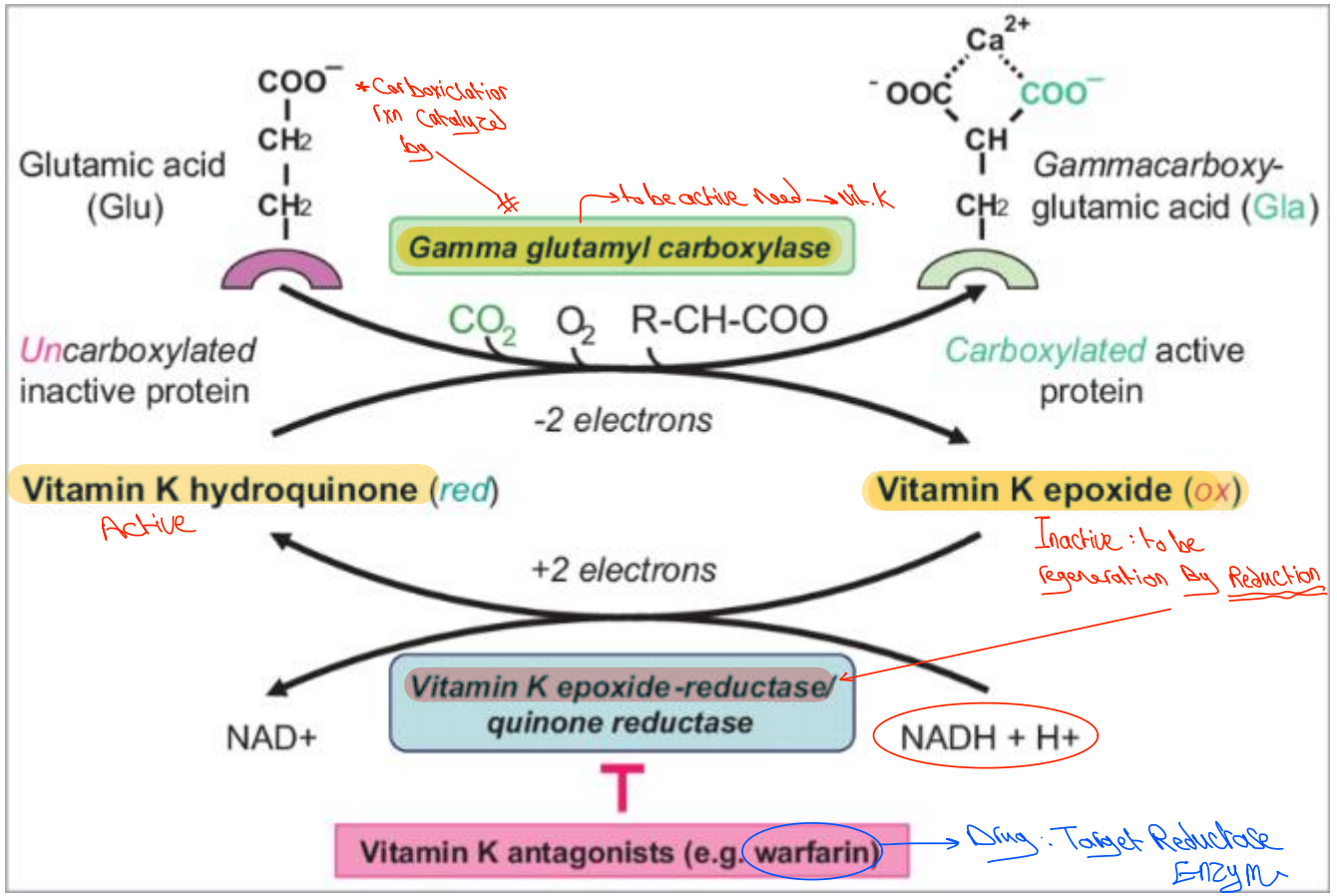






The role of vitamin K

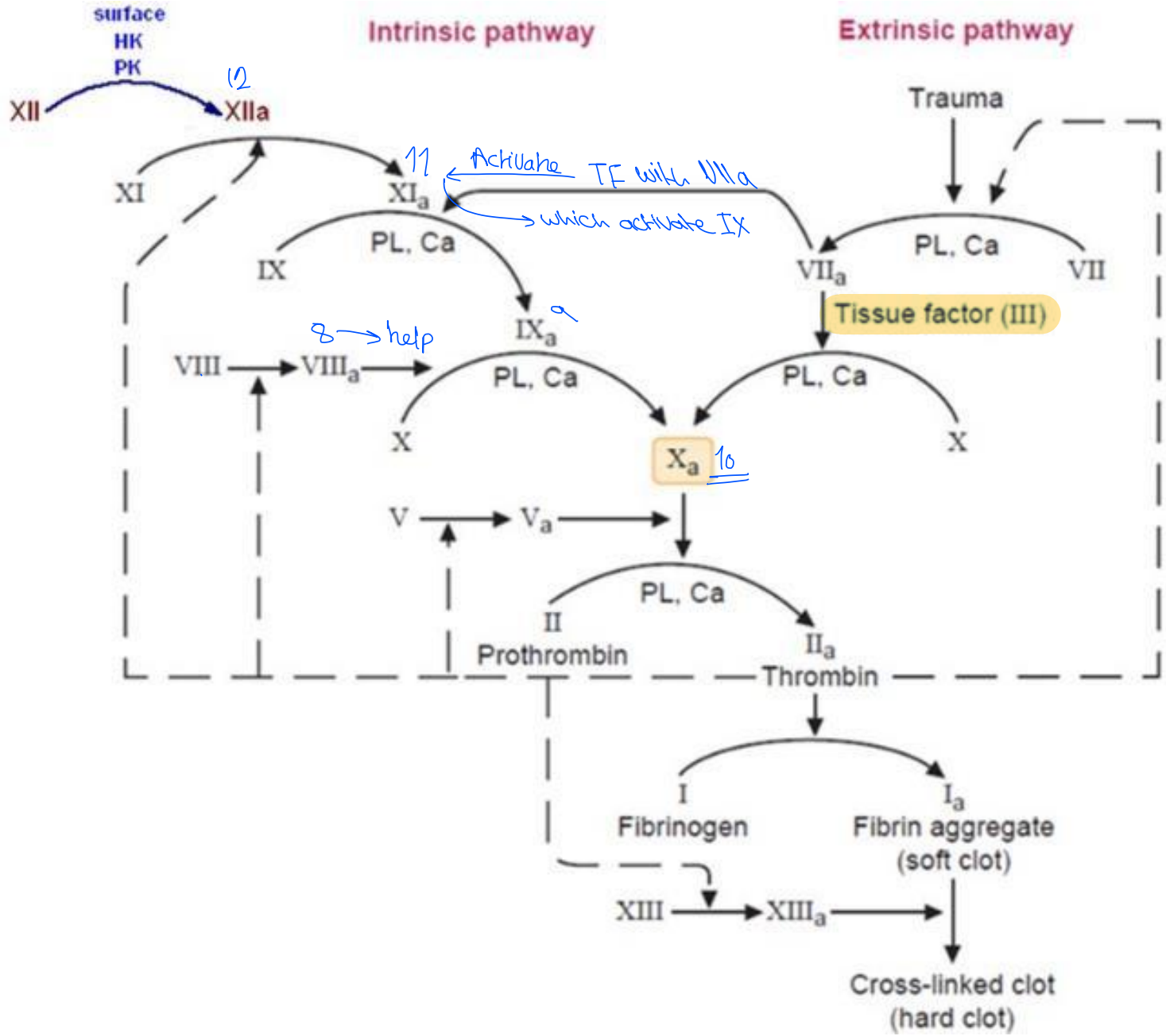
- Vitamin K participates in the conversion of Glu to γ-carboxy-Gla.
- Vitamin K becomes oxidized and must be regenerated.



Newborns and vitamin K deficiency

- Newborns are at risk for early vitamin K deficiency bleeding. Why?
  - The placenta is a poor passage channel for fat-soluble compounds, including vitamin K.
  - Neonates are born with an immature liver that impairs coagulation factor synthesis and GLA modifications.
  - Breast milk is a poor source of vitamin K.
  - Intestinal flora, the main source of vitamin K, is not established yet.

So, Rare to have Deficiency in Vit.K → Except who take Anti-Biotic for Long time

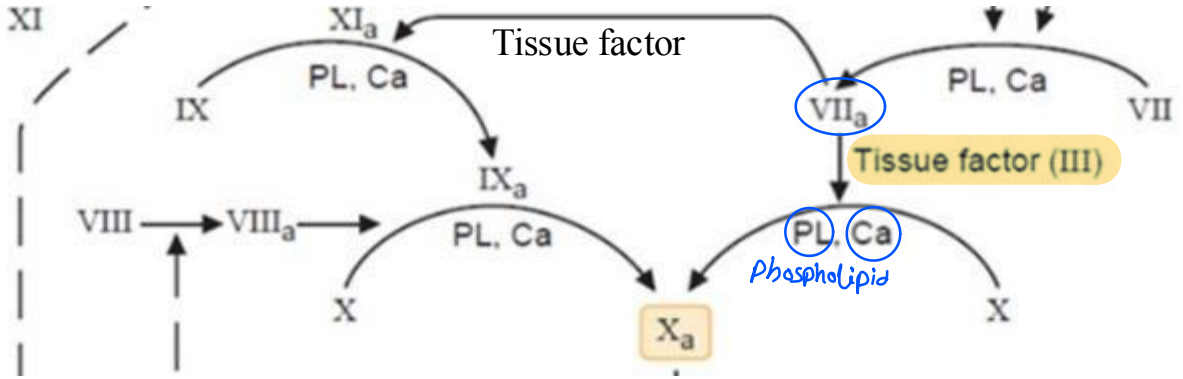

surface
HK
PK
XII
XIIa
12
Intrinsic pathway
Extrinsic pathway
Trauma
XI
XIa
11
Activate TF with VIIa
which activate IX
IX
PL, Ca
VIIa
PL, Ca
VII
Tissue factor (III)
IXa
9
8 → help
VIII
VIIIa
PL, Ca
PL, Ca
X
X
Xa
10
V
Va
PL, Ca
II
Prothrombin
IIa
Thrombin
I
Fibrinogen
Ia
Fibrin aggregate
(soft clot)
XIII
XIIIa
Cross-linked clot
(hard clot)

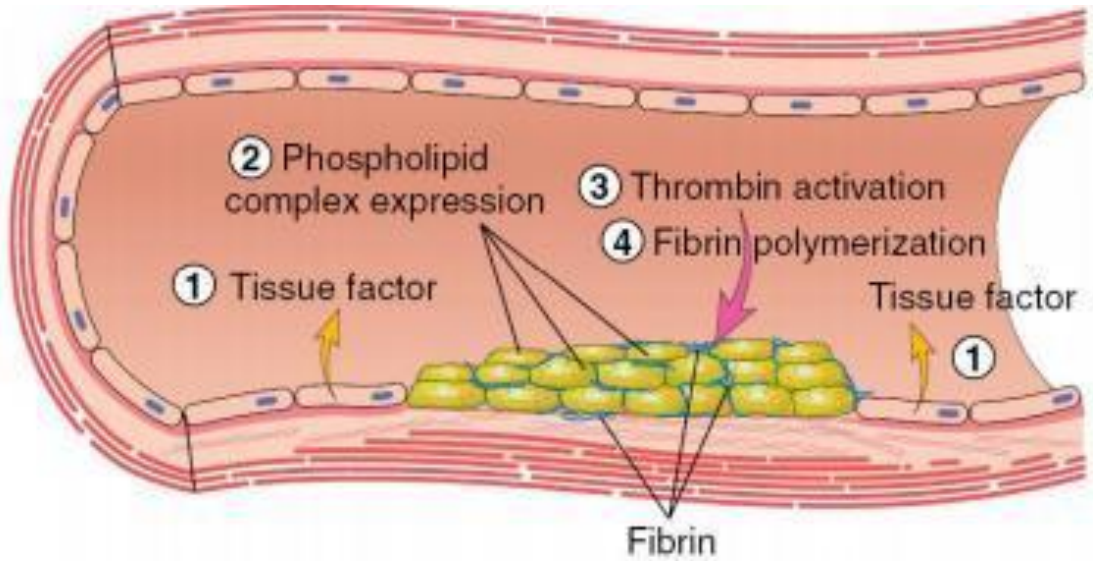
Start with Extrinsic

Tissue factor → released from damaged cells.

- TF is an integral membrane protein that is expressed on the surface of "activated" monocytes, subendothelial cells, and other cells.
- It is the primary initiator of coagulation and is not exposed to blood until disruption of the vessel wall.
- It increases the proteolytic efficiency of VIIa.

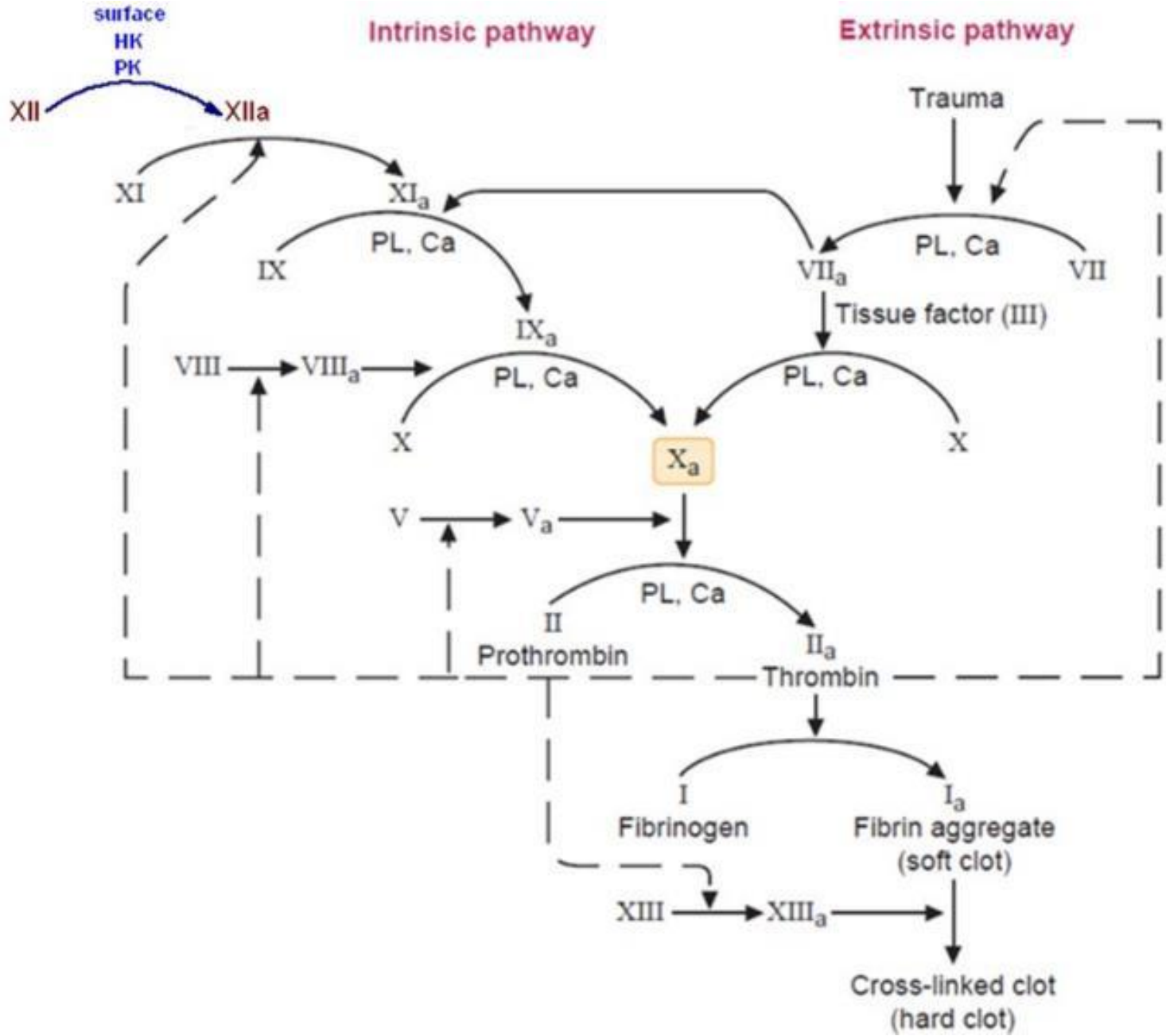
also, Tissue factor & VII → Activate to Intrinsic pathway



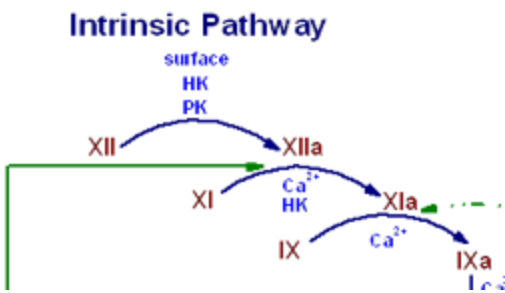


Exposure of tissue factor initiates the coagulation cascade.

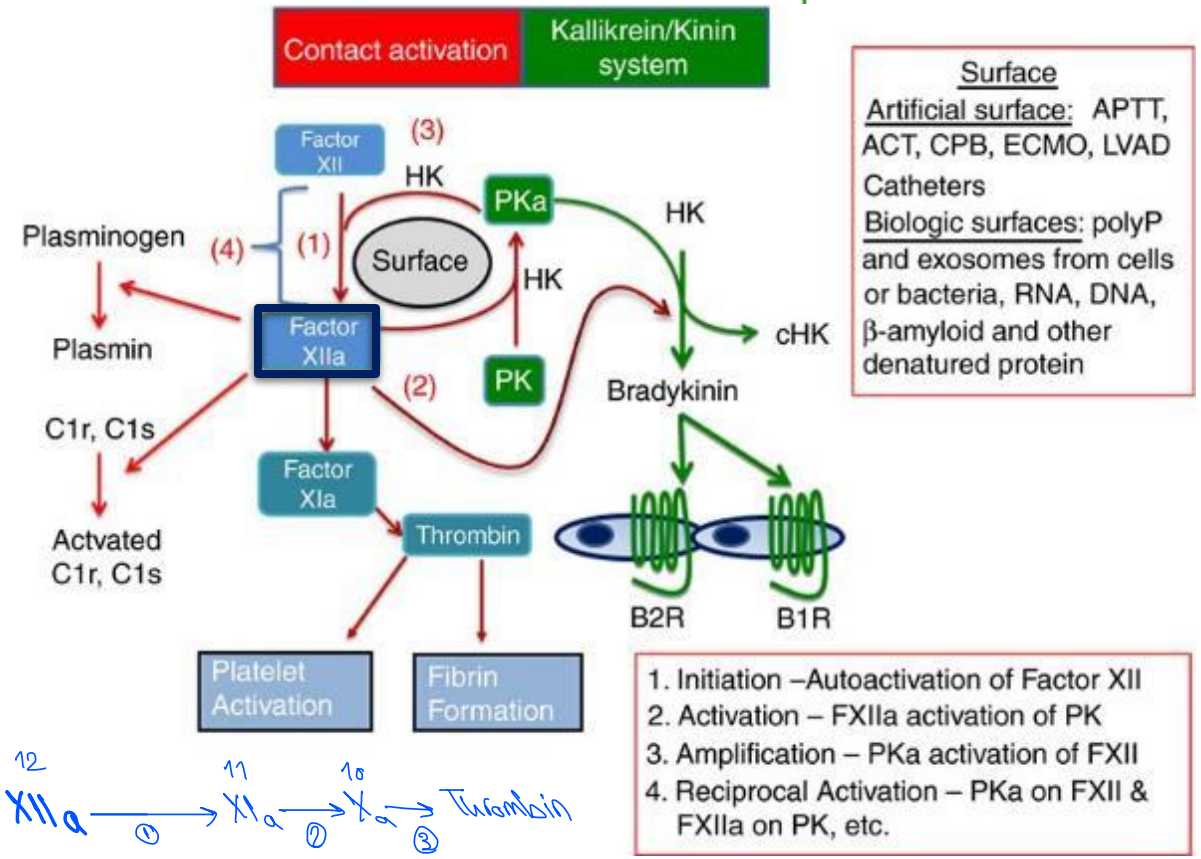
TF/VIIa complex is the "initiation complex".


surface
HK
PK
XII
XIIa
Intrinsic pathway
Extrinsic pathway
Trauma
XI
XI_a
IX
PL, Ca
IX_a
VIII
$VIII_a$
PL, Ca
X
X_a
VII_a
PL, Ca
VII
Tissue factor (III)
PL, Ca
X
V
V_a
II
Prothrombin
PL, Ca
II_a
Thrombin
I
Fibrinogen
I_a
Fibrin aggregate
(soft clot)
XIII
$XIII_a$
Cross-linked clot
(hard clot)

Initiation of the intrinsic pathway



- Prekallikrein, HMW kininogen, factors XII and XI are exposed to a negatively charged activating surface. (platelets)
- Factor XII is autoactivated into XIIa, which has several substrates:
  1. factor XI, which activates factor IX.
  2. Kallikrein from prekallikrein (note the positive feedback activation loop).
  3. HMW kininogen releasing bradykinin (a peptide with potent vasodilator action).
     - Bradykinin is also generated by kallikrein.
  4. Other substrates: plasminogen (fibrinolysis) and complement system proteins.

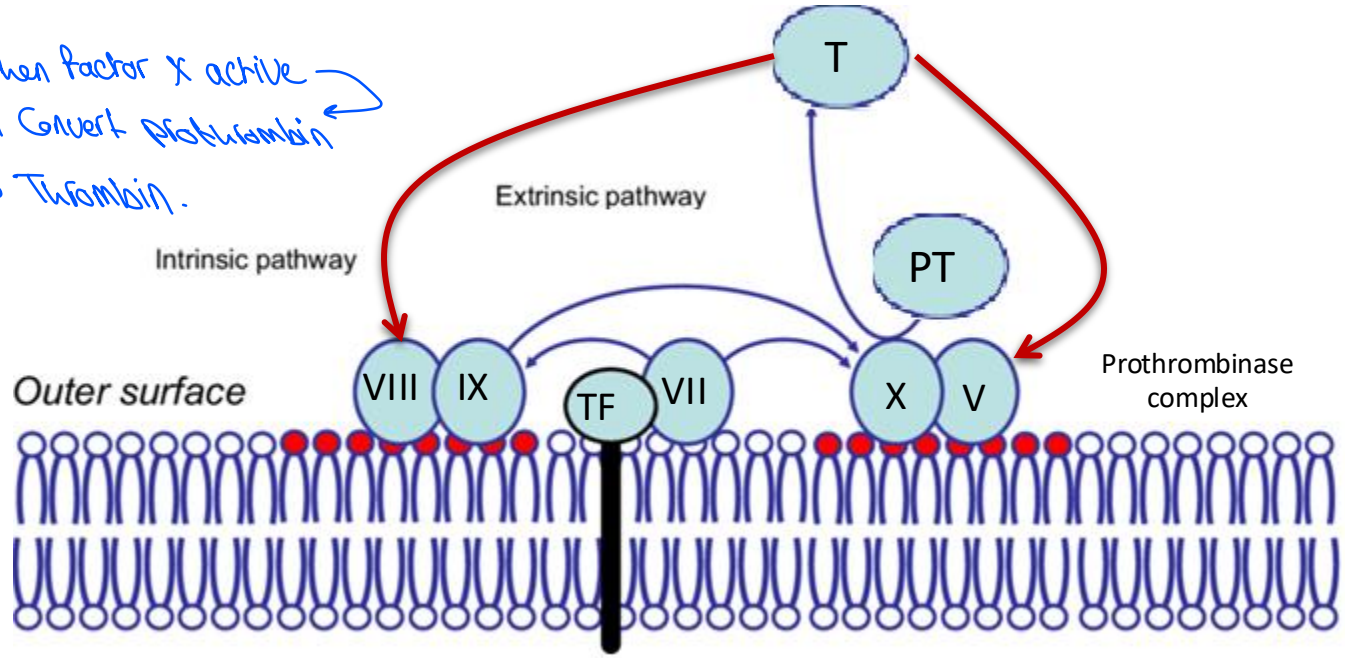


HK, intact high-molecular-weight kininogen; HKc, cleaved high-molecular-weight kininogen; PK, prekallikrein; PKa, plasma kallikrein; polyP, polyphosphate

The tenase complexes

- The activating complexes of factor X are called the "tenase" complexes.
  - The extrinsic tenase complex is made up of tissue factor, factor VIIa, and Ca^{2+}.
  - The intrinsic tenase complex contains the active factor IX (IXa), its cofactor factor VIII (VIIIa), and Ca^{2+}.
    - Tissue factor and factor VIIa also activate factor IX in the intrinsic pathway.

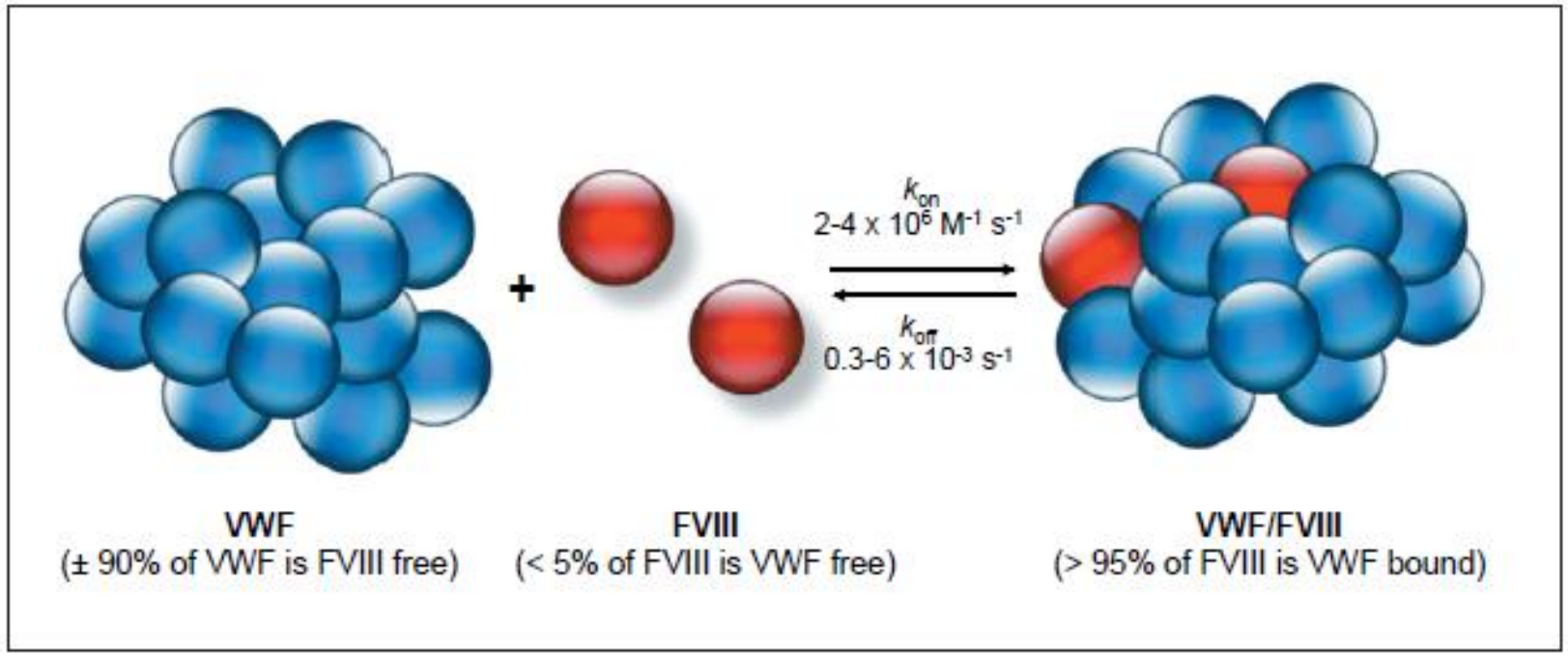
- Va and VIIIa are cofactors that increase the proteolytic efficiency of Xa and IXa, respectively.
  - Both factors V and VIII are activated by thrombin via a feedback mechanism.

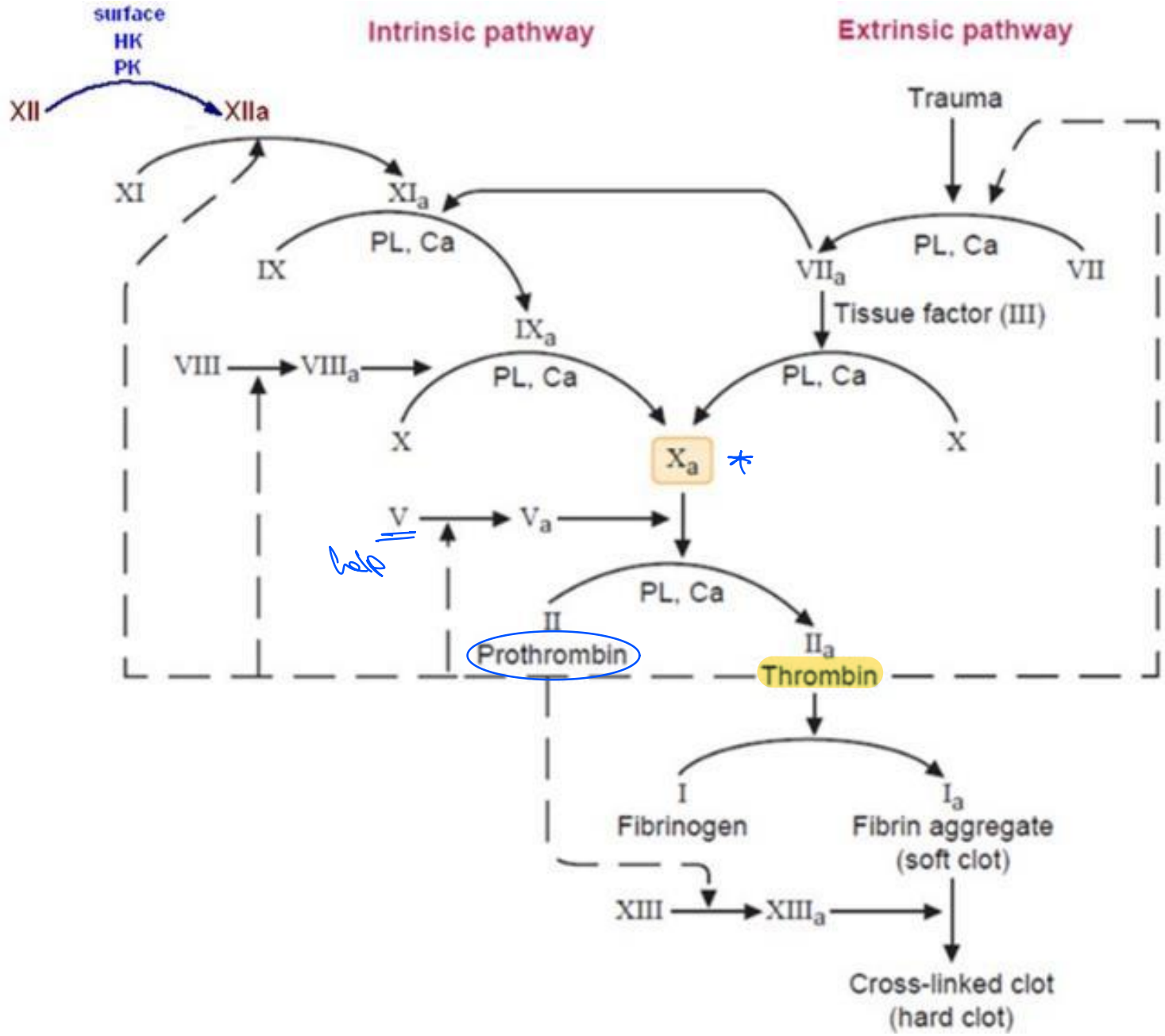


Released from endothelial cells & platelets → will bind to VIII

von Willebrand factor deficiency

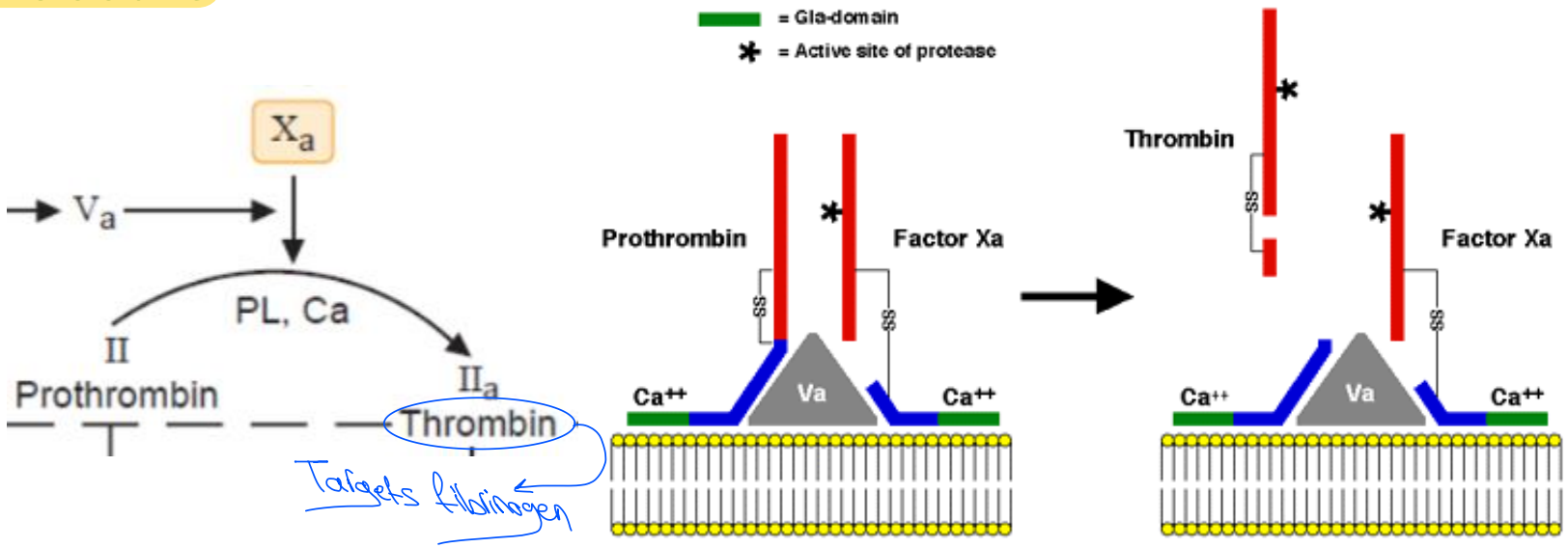
- Factor VIII circulates in plasma bound to von Willebrand factor, which increases VIII half-life, and, when released, it gets activated.
  - von Willebrand factor deficiency is associated decrease in the plasma concentration of factor VIII.




surface
HK
PK
XII
XIIa
Intrinsic pathway
Extrinsic pathway
Trauma
XI
XIa
PL, Ca
IX
VIIa
PL, Ca
VII
Tissue factor (III)
IXa
VIII
VIIIa
PL, Ca
PL, Ca
X
X
Xa
V
Va
PL, Ca
II
Prothrombin
IIa
Thrombin
I
Fibrinogen
Ia
Fibrin aggregate
(soft clot)
XIII
XIIIa
Cross-linked clot
(hard clot)

Prothrombin activation

- The complex of factor Xa/Va/Ca^{2+} is the "prothrombinase complex".
- Factor Xa converts prothrombin to thrombin, which is accelerated by Va, platelets (or phospholipids), and calcium ions.
- Binding of calcium alters the conformation the Gla domains of these factors, enabling them to interact with a membrane surface of platelets.
- Aggregated platelets provide the surface upon which prothrombin activation occurs .



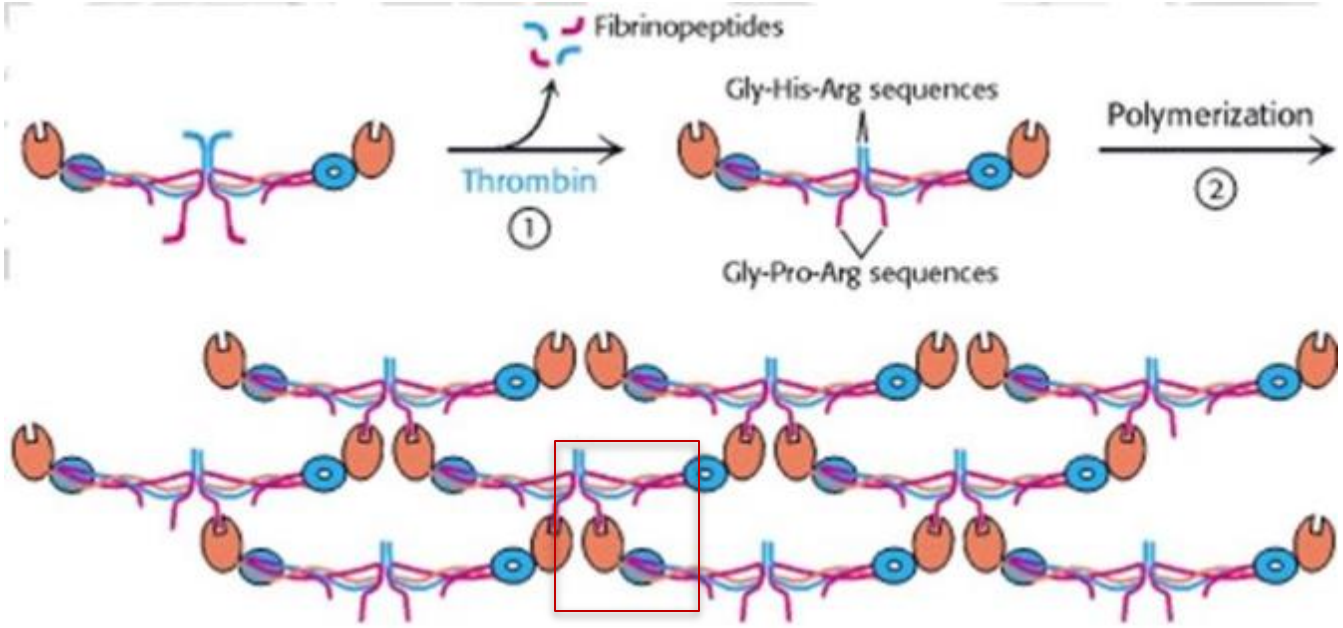
Formation of a *soft* fibrin clot

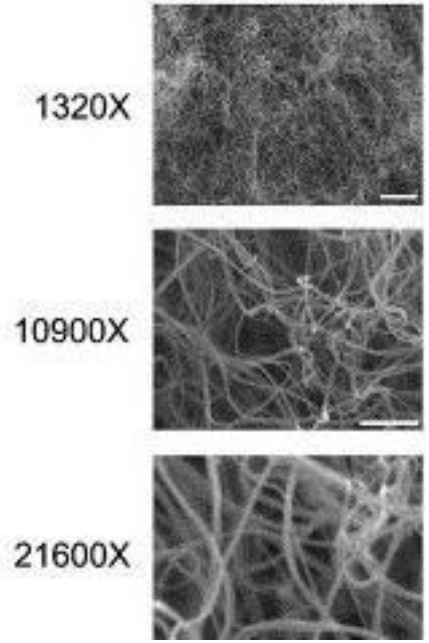
fibrinogen
(Thrombin) → release fibrinopeptides
fibrin monomers
Electrostatic interactions (non-covalent)
long polymers (soft clot) → bcs

- Thrombin cleaves fibrinogen releasing fibrinopeptides.
- Fibrinogen is a two triple-stranded helical protein held together by disulfide bonds.

* Separate molecule ← bcs of fibrinopeptides

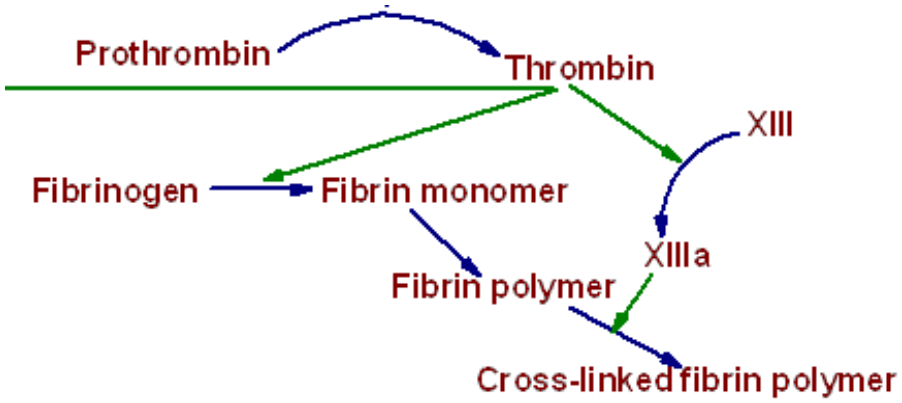
- Fibrin molecules create electrostatic attractions among each other facilitating the aggregation of the monomers into a gel consisting of long polymers.
- The clot resulting from aggregation of fibrin monomers is referred to as the "soft clot".

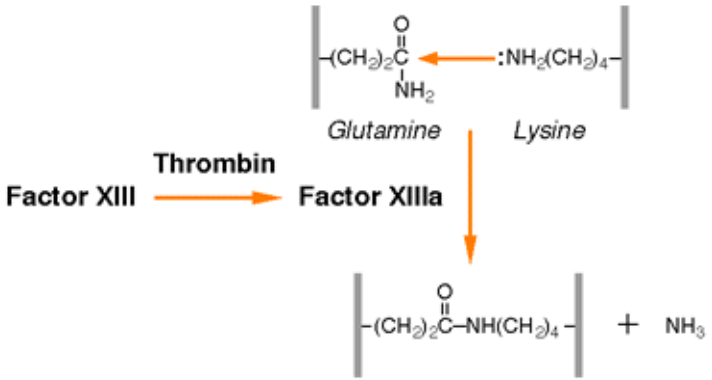


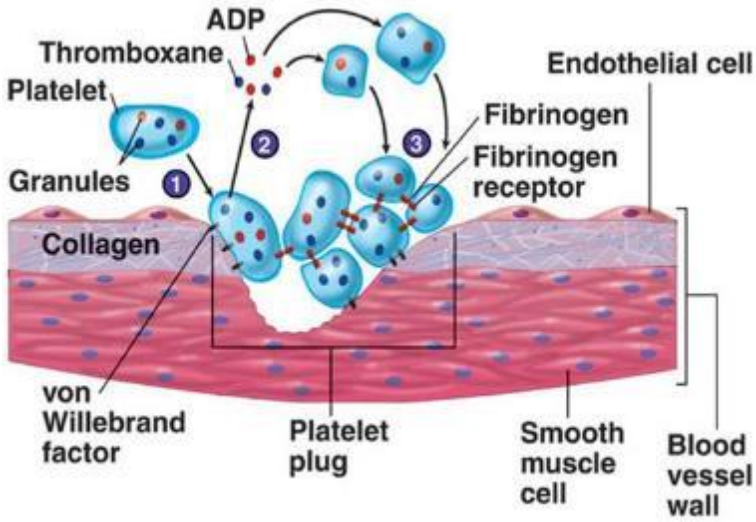


The formation of a hard clot by factor XIII

- Factor XIII is a transglutaminase that is activated by thrombin.
- Factor XIIIa catalyzes a transglutamination reaction that causes a covalent cross-linking reaction between a glutamine of one fibrin monomer to a lysine of an adjacent fibrin monomer.
  - It also cross-links the fibrin clot to adhesive proteins on the endothelial tissue and to the platelet surfaces strengthening the platelet plug.
  - The cross-links strengthen the fibrin mass, forming the "hard clot"



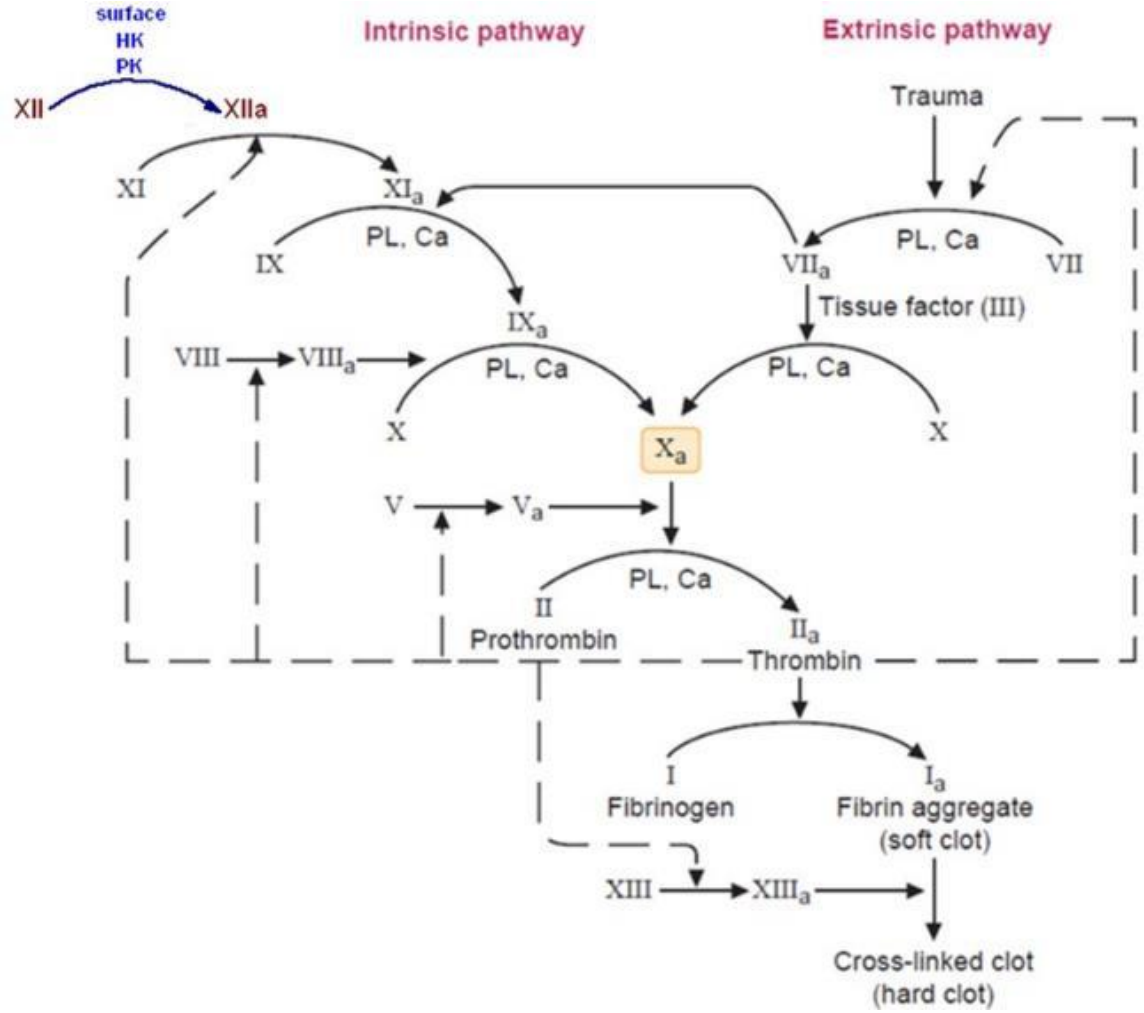




Amplification of coagulation reactions

↳ even in extrinsic / intrinsic

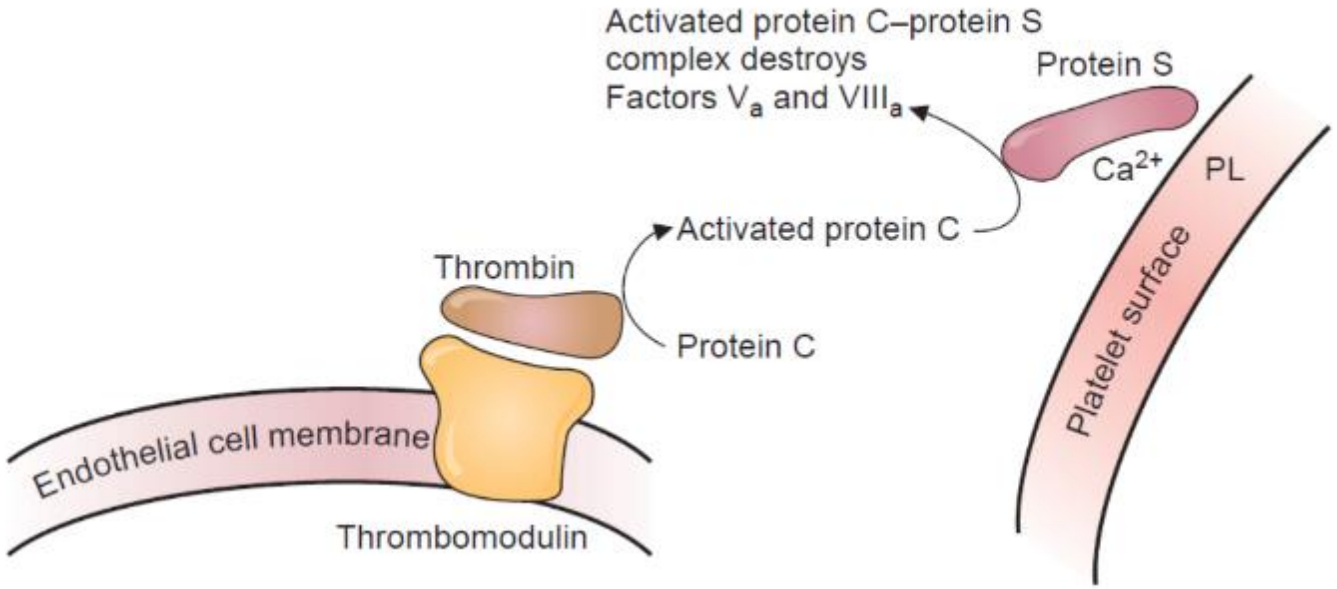
- The sequential enzymatic activation allows for amplification.
- Amplification also results from positive feedback reactions.
- These include activation of V, VII, VIII, and XI by thrombin.

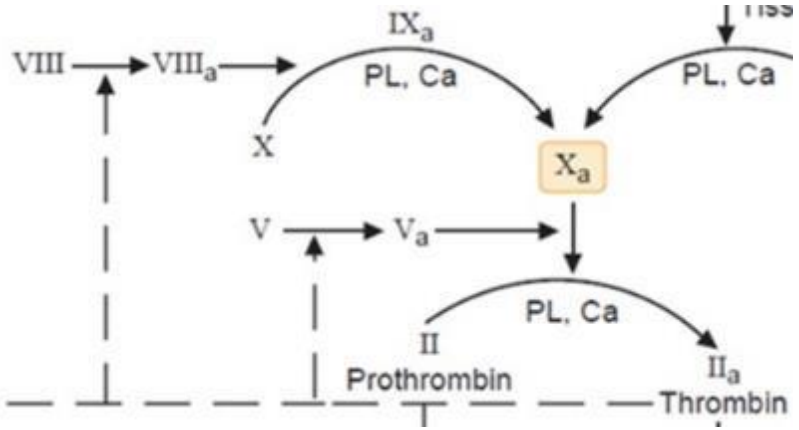


Anti-clotting factors

Protein C and protein S

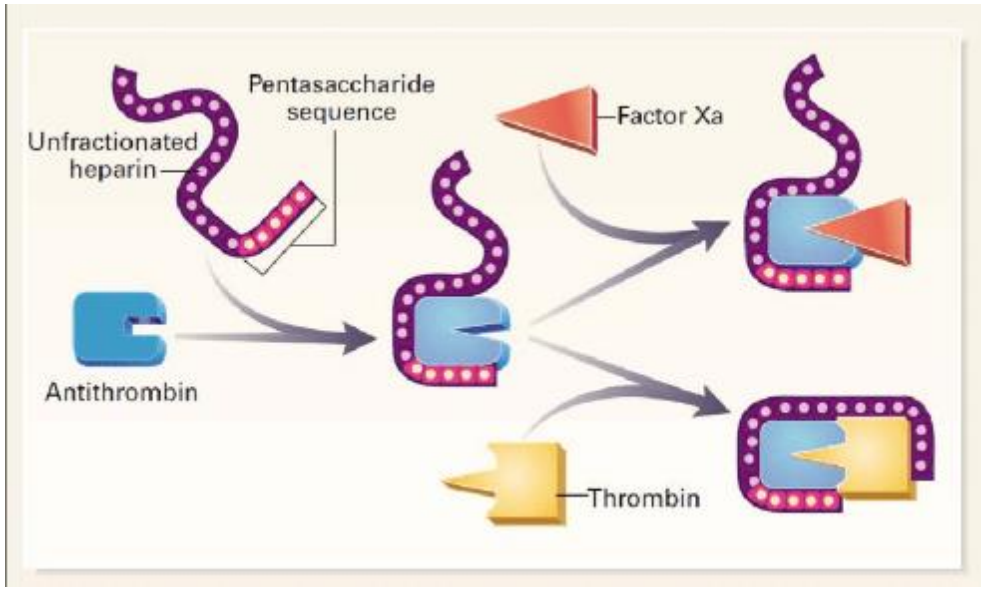
- Thrombin binds thrombomodulin on the surface of endothelial cells.
- Thrombin can then activate protein C, which forms a complex with protein S, both of which are vitamin K-dependent cofactors.
- The complex degrades factors V and VIII.

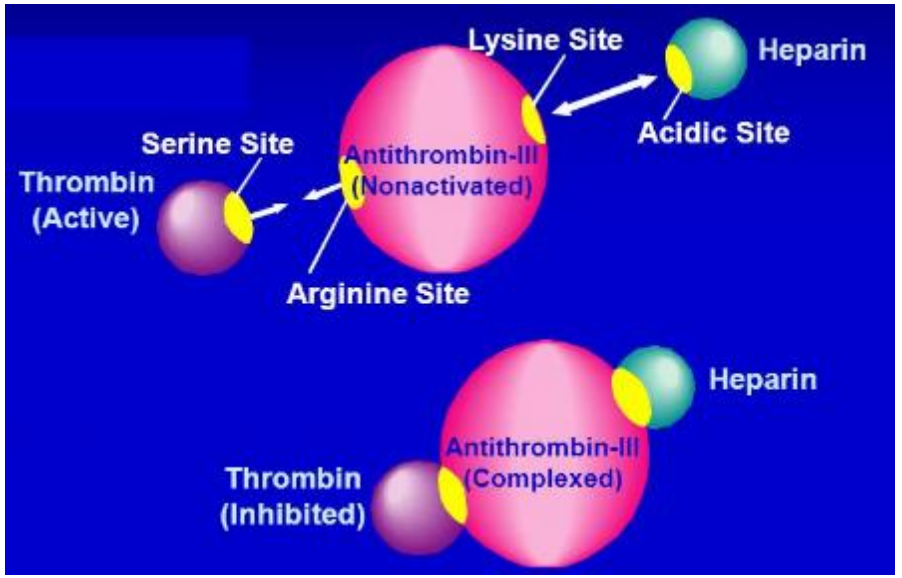




Antithrombin III

- Antithrombin III is a protease inhibitor of thrombin as well as an inhibitor of IXa, Xa, XIa, XIIa, and VIIa when complexed with TF.
- Heparin sulfate, a polysaccharide synthesized by mast cells and present on the surface of endothelial cells, binds to antithrombin III, promoting binding to its substrates.

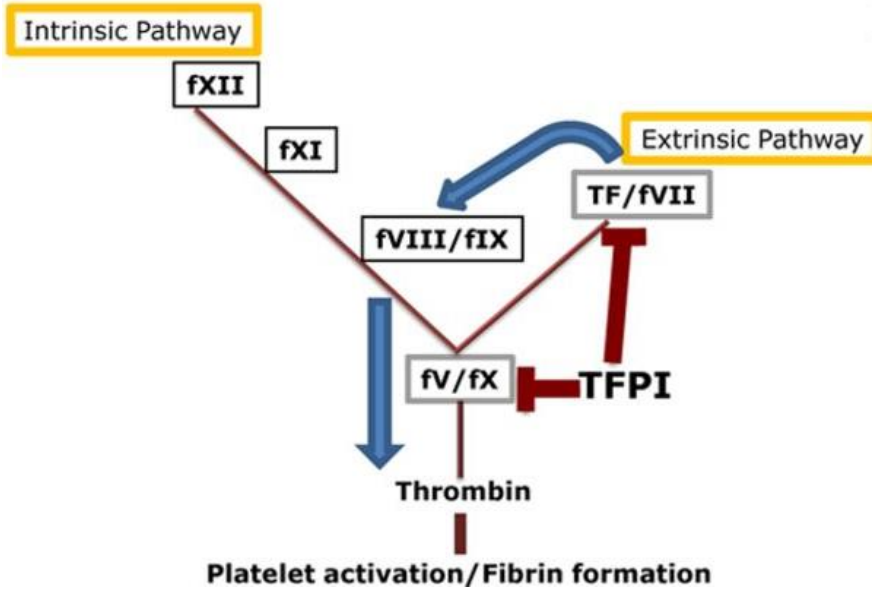


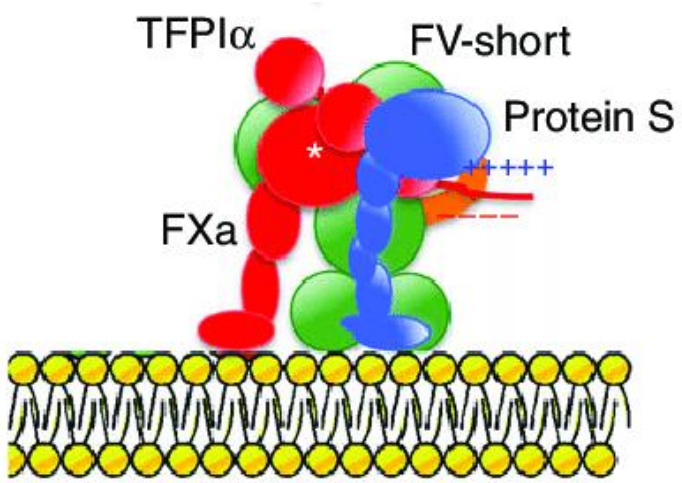


In the clinic, phlebotomy tubes are often treated with heparin to inhibit clot formation.

Tissue Factor pathway inhibitor

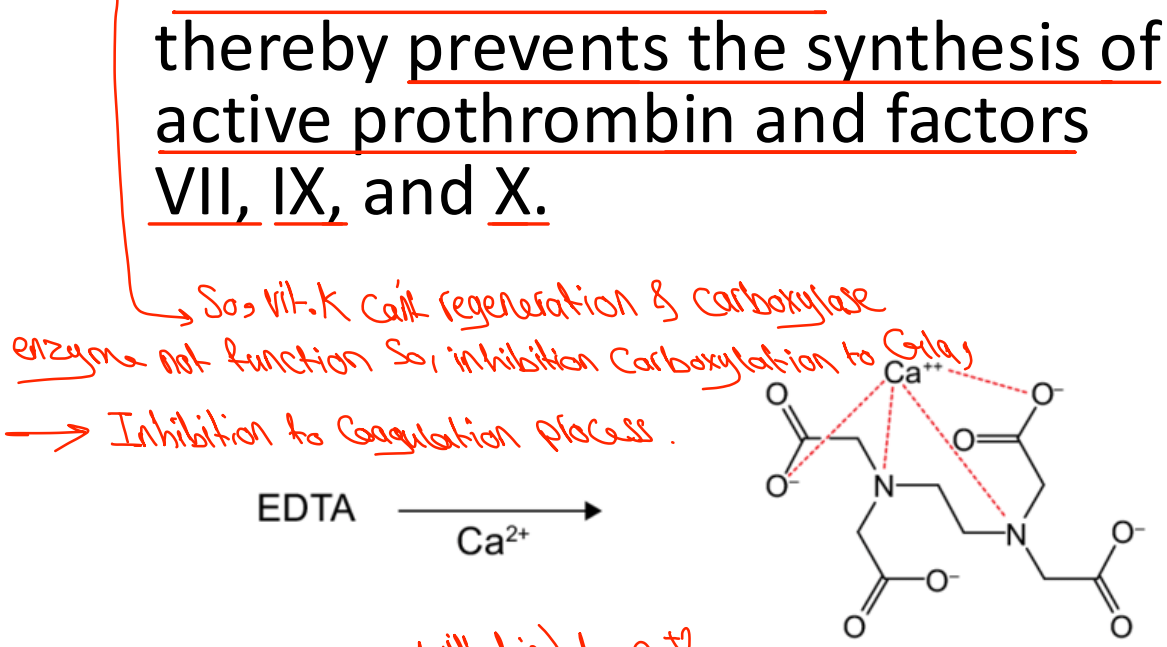
- Tissue factor pathway inhibitor (TFPI) is a protein found in plasma lipoproteins and bound to the vascular endothelium.
  - It binds to and inhibits factor Xa.
  - The Xa-TFPI complex then interacts with the TF-VIIa complex and inhibits its activation of factors X and IX.
  - TFPI also inhibits Xa-activated Va resulting in inhibition of the pro-thrombinase complex.
  - Protein S binds to TFPI localizing it to membrane surfaces and enhancing the inhibition of Xa., inhibiting



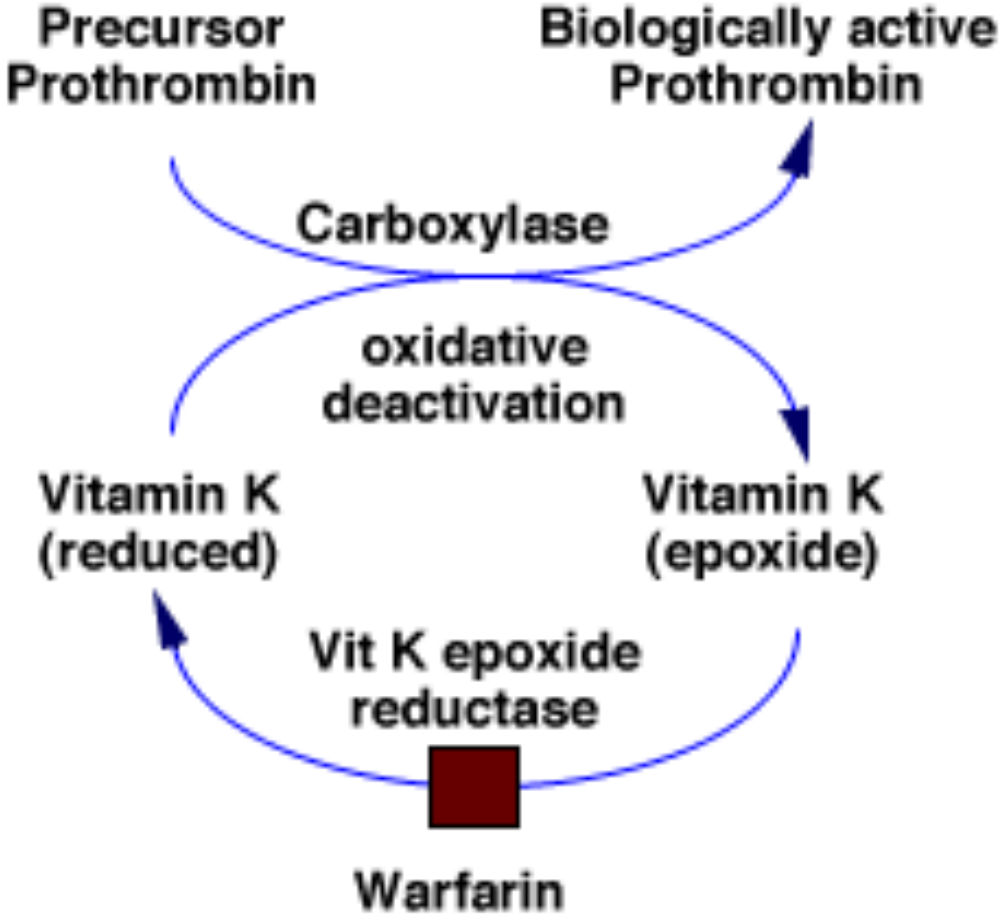


Ca^{2+} chelators and vitamin K antagonists

- Blood clotting can be prevented by addition of Ca^{2+} chelators and vitamin K antagonists such as the drug warfarin, which inhibits the reduction of vitamin K and thereby prevents the synthesis of active prothrombin and factors VII, IX, and X.



Calcium-EDTA



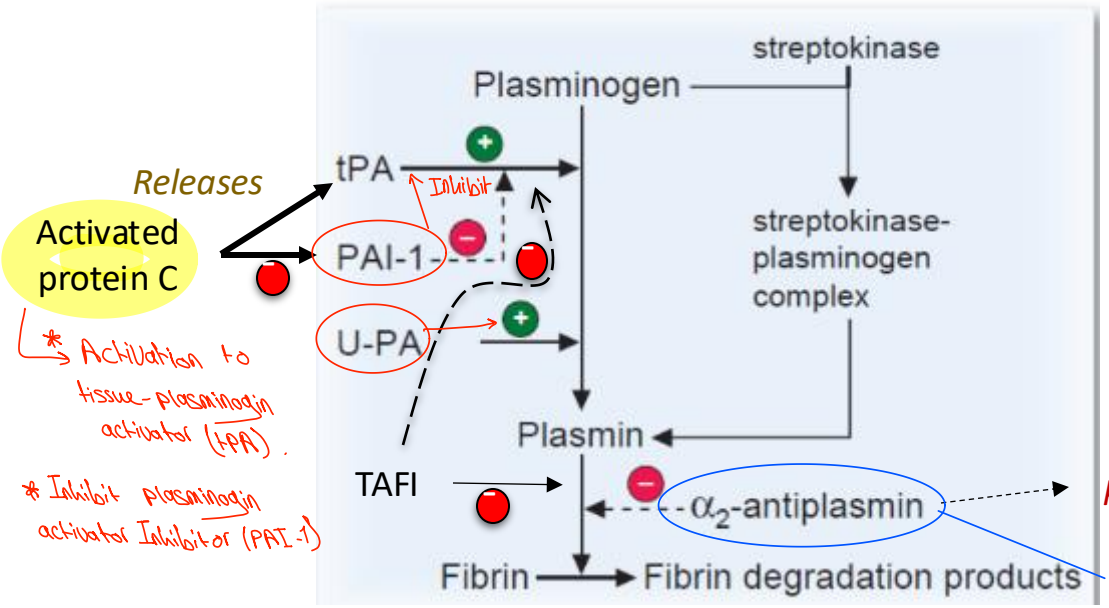
Degradation of the fibrin clot

Clot dissolution

- It is important to prevent clot formation when not needed by anti-clotting factors and to dissolve a clot when formed.
- Clot dissolution starts concomitant with its formation.
  - By plasmin

The fibrinolytic system

- Plasmin is a protease formed from plasminogen and is responsible for fibrinolysis where it binds to fibrin and catalyzes its hydrolysis.
  - Plasminogen has a high affinity for fibrin clots.
- Thrombin activatable fibrinolysis inhibitor (TAFI) is a carboxypeptidase that removes the N-terminal lysine residues and prevents fibrinolysis.

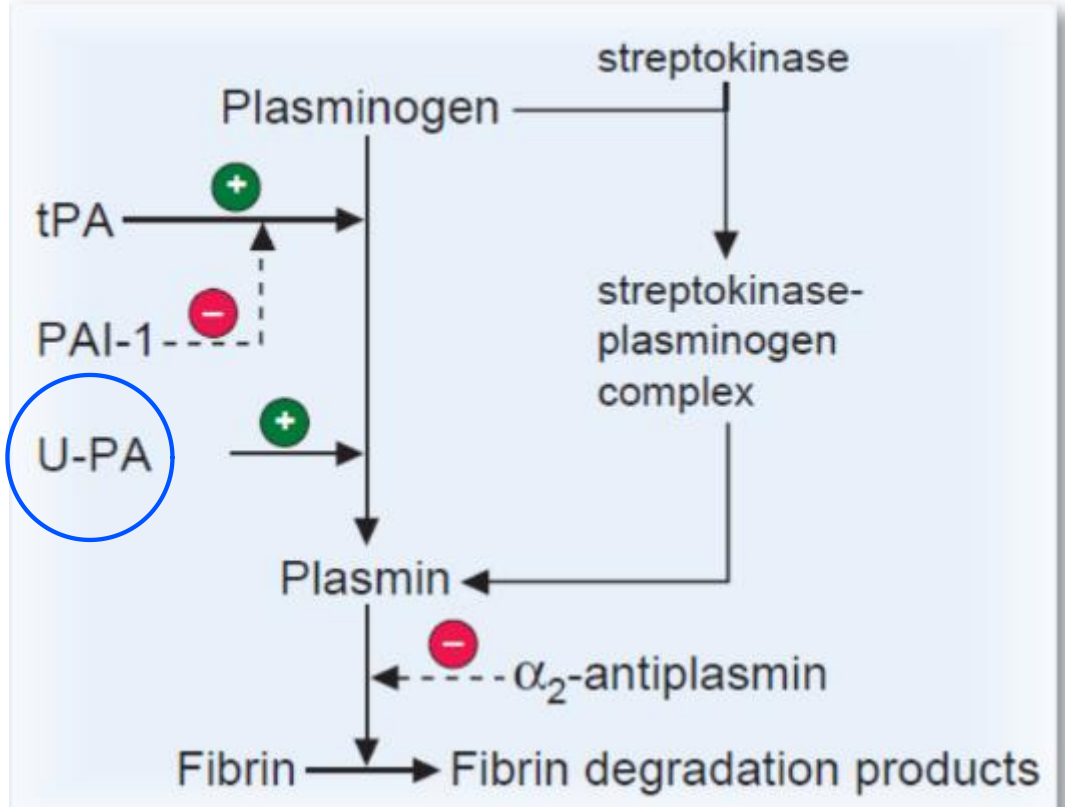


Streptokinase, a regulatory protein isolated from streptococci, allows autoactivation of plasminogen in blood, resulting in degradation of fibrinogen as well as fibrin.

but not when plasminogen/plasmin are clot-bound

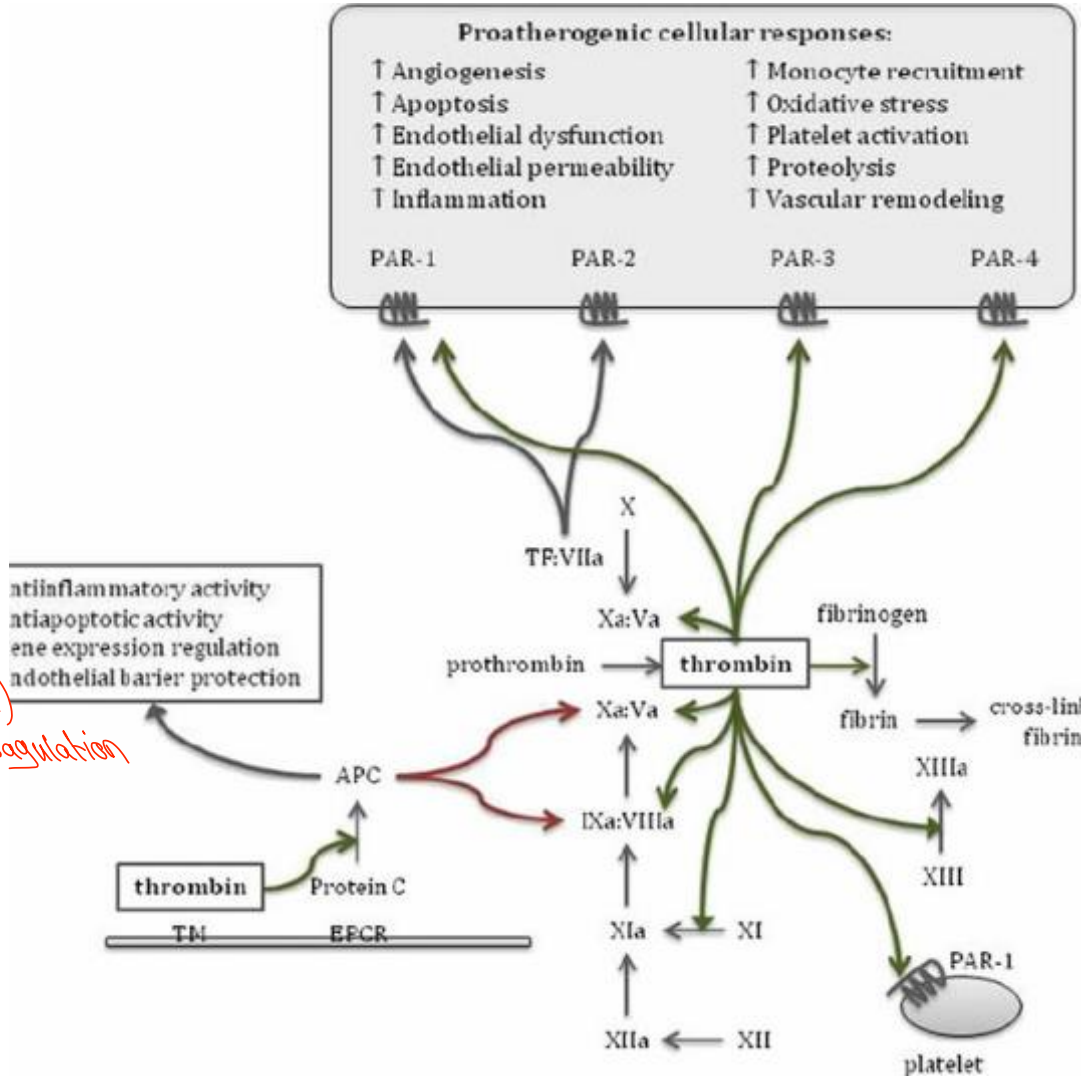
Urokinase

- Urokinase (plasminogen activator) is a protease that is formed from the zymogen pro-urokinase.
- It is a potent plasminogen activator and is used clinically. to remove clot in patient.

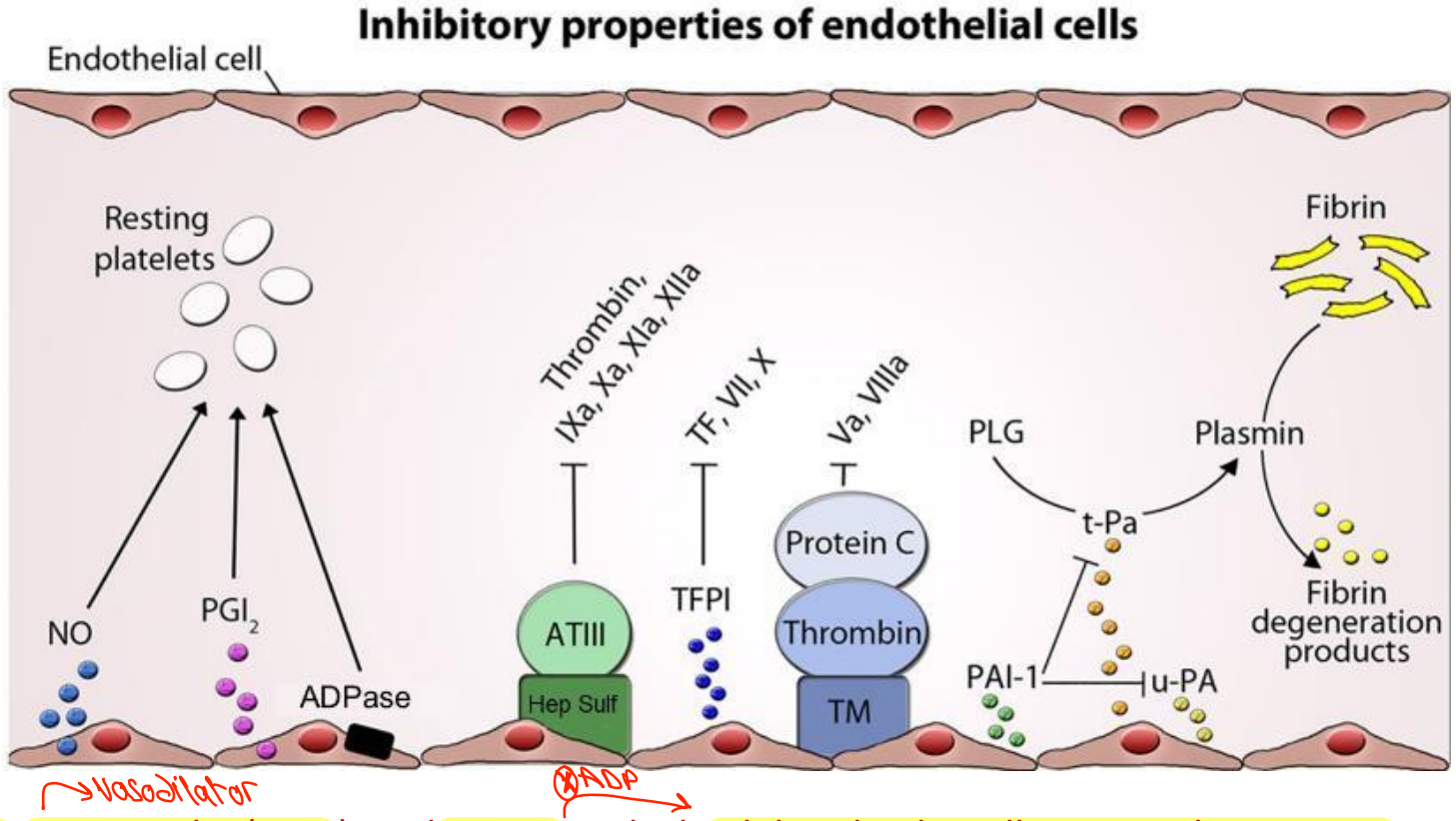


Roles of thrombin

- Platelet recruitment
- Amplification of the coagulation complex
- Formation of soft clot
  - Proteolytic cleavage of fibrinogen
- Formation of hard clot
  - Activation of factor XIII
- Attenuation of its own activity
  - Activation of protein C
- Other actions
  - Binding to its receptor on the surface of platelets induces vascular remodeling (e.g. angiogenesis) and inflammation.



Role of endothelial cells in coagulation



- ECs release NO, prostacyclin (PGI2), and ADPase, which inhibit platelet adhesion and aggregation.
- Membrane-bound heparin sulfate binds to antithrombin III (ATIII) inactivating several coagulation factors.
- ECs express tissue factor pathway inhibitor (TFPI), which inhibits tissue factor (TF) and, consequently, factors VII, IX, and X.
- Thrombomodulin (TM) binds thrombin activating protein C, which degrades factors Va and VIIIa.
- ECs balance fibrin accumulation and lysis by releasing plasminogen activators, t-PA and u-PA, and their inhibitor (PAI).

Neubauer and Zieger. Endothelial cells and coagulation. Cell and Tissue Research (2021)

It is a symphony played by an orchestra.