HEMATO LYMPHATIC SYSTEM

BIOCHEMISTRY

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Blood Coagulation

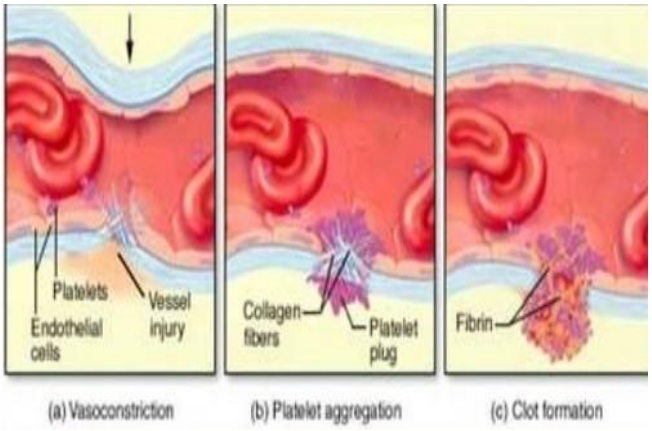
What is blood coagulation (clotting)?

it describes 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 **(hemo: blood, stasis: stoppage; the cessation of blood loss)** followed by clot dissolution and repair.

the word orchestrated means that it's almost like a classical music, so it stars **slow** and then it goes **up and up and up** until it reaches a climax then you see the music is going **down** reaching the end. it's basically a symphony.

-> Steps of hemostasis

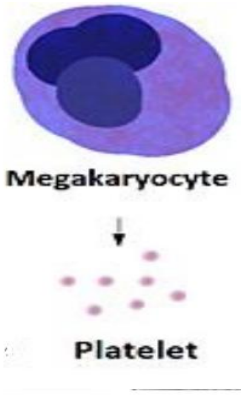
1- Vascular constriction limiting blood flow to the area of injury. **(physiological effect)**
2- Activation then aggregation of platelets at the site of injury, forming a **loose platelet plug**.
3- Formation of a fibrin mesh to entrap and solidify the plug, so it is called a **hard clot**. **(cellular & biochemical process)**
4- Dissolution of the clot for normal blood flow to resume following tissue repair.

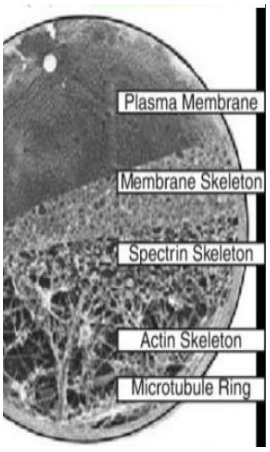


platelets are a major player

platelets are small anuclear cell fragments produced from the megakaryocytes.
they have:

- ✓ plasma membrane.
- ✓ numerous kinds of surface receptors.
- ✓ actin filaments and myosin **which change the shape of the platelet upon activation**.
- ✓ three types of granules **that store substances which are released upon platelet activation.**
- ✓ Signaling factors and proteins





Granules:

- ❖ **Electron-dense granules** (calcium ions, ADP, ATP, serotonin)

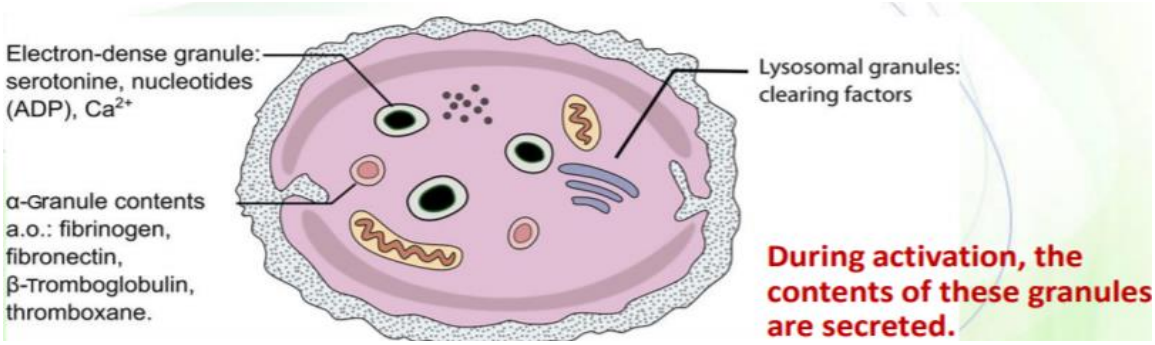
why do we have ATP and ADP inside these vesicles?
They are not used as source of energy rather they are used as signaling molecules.

- ❖ **α-granule** {a heparin antagonist, platelet-derived growth factor **(signaling molecule),** fibrinogen **(structural protein),** von Willebrand factor -vWF - **(regulatory protein),** clotting factors}

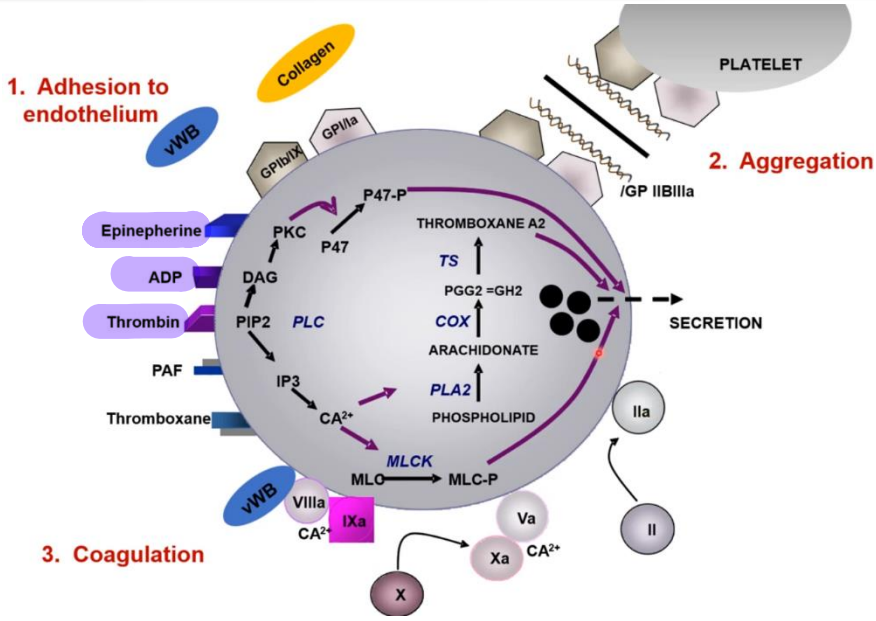
"**Heparin** is an anticoagulant."

- **Lysosomal granules** (hydrolytic enzymes) ➔ necessary for removal of the clot and activation of different proteins.

Again, once these platelets are activated upon vascular injury ➔ these granules fuse with the plasma membrane releasing their contents.



Platelets Surface



Notice the[1] numerous receptors on the platelet surface [for example, there are receptors for epinephrine, ADP and thrombin]. All of these receptors activate G-protein.

There are a lot of[2] glycoproteins which are important for interacting with vWF, collagen and fibrinogen and for forming aggregation of platelets at the site of injury.

Also, on the platelet surface, the [3] process of blood coagulation takes place.

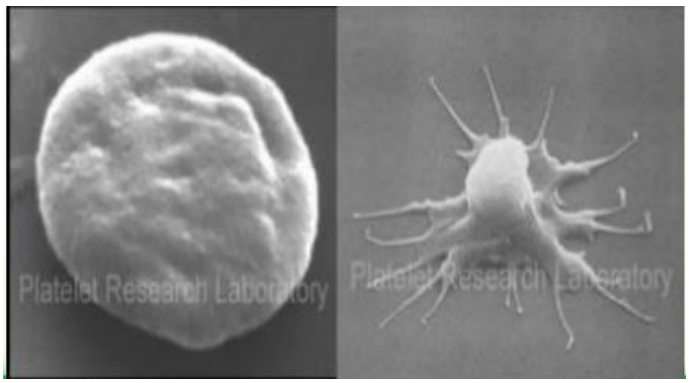
What exactly happens at the time of vascular injury?

1- Adhesion to endothelium:

Whenever there is a vascular injury, a protein known as Von Willebrand factor (from endothelial cells) and the collagen (subendothelial collagen) are exposed. This leads to the binding of the platelet glycoproteins with this factor activating the platelets [= generating a series of signaling reactions inside the platelets resulting in the secretion of several factors from the granules of the platelets].

** These factors are ADP, Serotonin, Factor V, ATP, Calcium, Fibrinogen, vWF, Thrombin, Thromboxane. → these factors bind to specific receptors.

=> Note: once the platelets are activated, their shape changes allowing for more platelet-platelet interaction and aggregation.



2- Aggregation:

As we mentioned earlier the **glycoproteins** on the platelet surface are important for forming aggregation of platelets at the site of injury.

3- Coagulation

Some important molecules are involved in the process of coagulation:

1- Thrombin receptor:

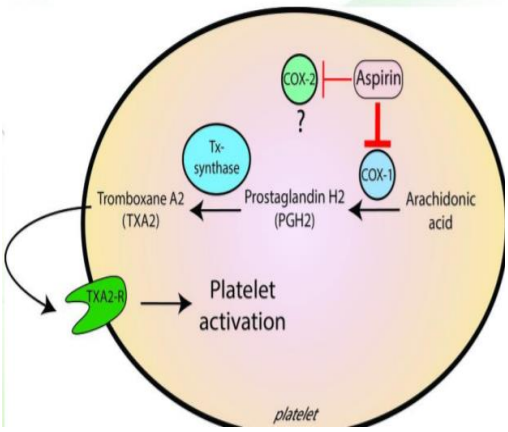
- Thrombin receptor activates a **G-protein** that activates phospholipase C-β (**PLC-β**)
- **PLC-β** nydrolyzes phosphatidylinositol-4,5- bisphosphate (**PIP2**) into inositol trisphosphate (**IP3**) and diacylglycerol (**DAG**).
- **IP3** induces the release of intracellular **Ca2+** stores, and **DAG** activates protein kinase C (**PKC**).
- **Calcium** activates the enzyme **phospholipase A2** that triggers liberation of **arachidonic acid** from membrane phospholipids.
- **Arachidonate** is converted by **cyclooxygenase 1** to **prostaglandins**, which are then converted by **thromboxane synthetase** to **thromboxane A2**.

⇨ Once **thromboxane A2** is released, it has vasoconstrictor activities (limiting blood flow) and it is a platelet activator (helps in the aggregation of the platelet.)

⇨ **It acts in autocrine and paracrine manners**: it can bind to its receptor on the cell surface of the same cell that secreted it , thus activating signal transduction pathway inside, it can also act on neighboring places as well.

As we said, **cyclooxygenase1** converts **Arachidonate** into **prostaglandins** leading to the release of **thromboxane A2 .** (all of these are 20-carbon fatty acids)

-> Non-steroidal anti-inflammatory drugs (like Aspirin) inhibit the enzyme **cyclooxygenase1&2**, accounting for their anticoagulant effects. → preventing the formation of atherosclerosis.



Aspirin reduce the incidence of myocardial infraction because it reduces platelet aggregation and vasoconstriction

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

Aspirin -> irreversable inhibition to COX -> No TxA2 (vasoconstrictor) + No PGI2 (vasodilator)
Who does win the compitition?
PGI2 , because it is secreted by endothelial cells (neucleated cell) can regenerate COX
but platelets cannot

be cautious about prescribing aspirin specially to the elderly , the results of 2 clinical trails (were published in 2018) pointing out it can be harmful and causes excessive bleeding and hemorrhage in many cases

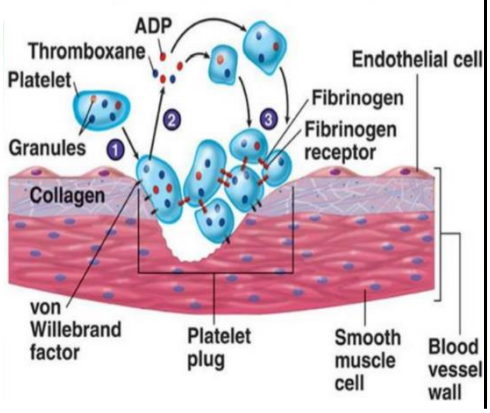
in addition to activation of phospholipase A2 and release of arachidonate from phospholipids, **Ca2+ ions** activate myosin light chain kinase (MLCK), which phosphorylates the light chain of myosin allowing it to interact with actin resulting in a number of effects: **altering platelet morphology** (more aggregation), **inducing motility** (because they modify the actin cytoskeleton) , and increasing the **release of granules**.

2- Serotonin (vasoconstrictor)
3- PDGF (Platelet-derived growth factor) which stimulates proliferation of endothelial cells to reduce blood flow.
4-ADP

Remember that, **DAG** activates **PKC**, which phosphorylates and activates specific platelet proteins (including P47) that induce the release of **platelet granule contents** including **ADP.**

the role of ADP

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 surface

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

Biochemistry of coagulation

Components of coagulation (they vary in size)

1- An organizing surface (platelets) **we've already talked about**
2- Proteolytic zymogens (prekallikrein, prothrombin, and factors VII, IX, X, XI, XII, and XIII)
***remember that zymogens are enzymes that require proteolytic cleavage in order to be active, example: trypsinogen which is converted to trypsin when it is cleaved**
***factors are mostly proteins designated with roman numbers**

These are mainly serine proproteases released from hepatocytes.
The subscript "a" designates the activated form of a factor. **e.g., once factor "XIII" is activated it's called "XIIIa"**

3- Anti-coagulants (protein C, protein S)
4- Non-enzymatic protein cofactors (factors VIII, V, and tissue factor)
5- Calcium ions
6- Vitamin K
7- Fibrinogen ;Forms the fibrin network

Clotting factor number	Clotting factor name	Function	Plasma half-life (h)
I	Fibrinogen	Clot formation	90
II	Prothrombin	Activation of I, V, VII, VIII, XI, XIII, protein C, platelets	65
III	TF	Co factor of VIIa	-
IV	Calcium	Facilitates coagulation factor binding to phospholipids	-
V	Proacclerin, labile factor	Co-factor of X-prothrombinase complex	15
VI	Unassigned		
VII	Stable factor, proconvertin	Activates factors IX, X	5
VIII	Antihaemophilic factor A	Co-factor of IX-tenase complex	10
IX	Antihaemophilic factor B or Christmas factor	Activates X: Forms tenase complex with factor VIII	25
X	Stuart-Prower factor	Prothrombinase complex with factor V: Activates factor II	40
XI	Plasma thromboplastin antecedent	Activates factor IX	45
XII	Hageman factor	Activates factor XI, VII and prekallikrein	
XIII	Fibrin-stabilising factor	Crosslinks fibrin	200
XIV	Prekallikerin (F Fletcher)	Serine protease zymogen	35
XV	HMWK- (F Fitzgerald)	Co factor	150
XVI	vWf	Binds to VIII, mediates platelet adhesion	12
XVII	Antithrombin III	Inhibits IIa, Xa, and other proteases	72
XVIII	Heparin cofactor II	Inhibits IIa	60
XIX	Protein C	Inactivates Va and VIIIa	0.4
XX	Protein S	Cofactor for activated protein C	

HMWK – High molecular weight kininogen; vWf – Von Willebrand factor; TF – Tissue factor

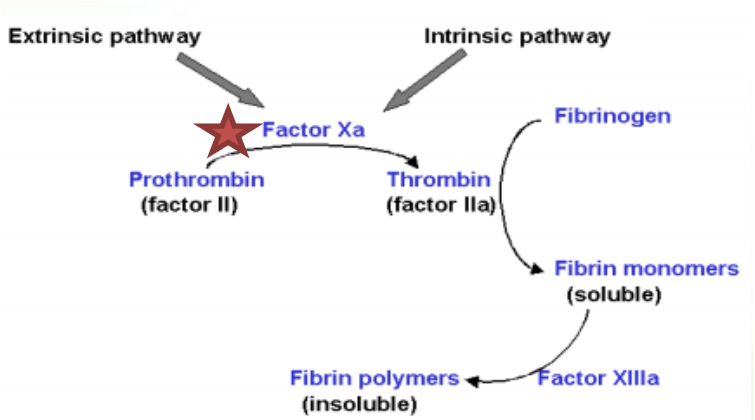
This is a list of the different clotting factors, their names, and what their functions are. Please refer to it after finishing the sheet to summarize the whole process.
These factors are not all proteins.
Notice that factor IV is Ca.

Two pathways included in coagulation:

1- **Intrinsic pathway**: is initiated when subendothelial surface (i.e., collagen) is exposed. That is as a result of internal effect like an inflammation.
2- **Extrinsic pathway**: is initiated in response to tissue injury.
So, here tissue factor (TF) protein is released.

These two pathways were thought to be independent, but later it was discovered that they are not totally independent, there is a bridge that connects them together, so whenever the extrinsic pathway is activated, the intrinsic is activated too.

3- However, the two pathways converge on a **common pathway**.



Extrinsic pathway:

Vascular injury (trauma) → exposure of collagen and vWF → activation of factor VII **(with the help of tissue factor)** → activation of factor X

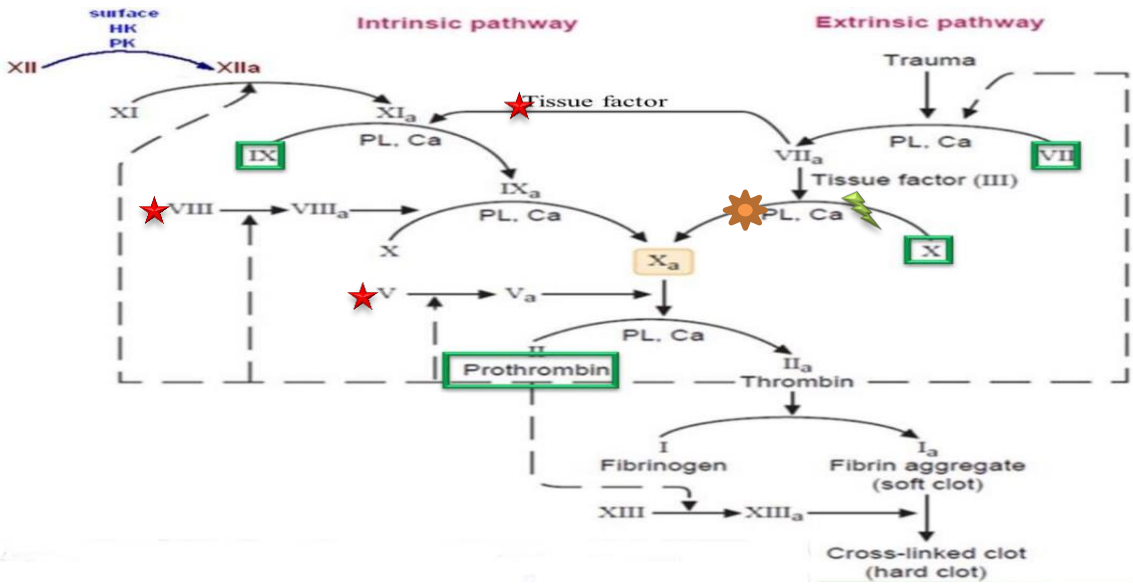
Intrinsic pathway:

In case of inflammation (there is also activation of the kallikreins-kinins pathway), there is activation of factor XII → activation of factor XI → activation of factor IX
* tissue factor also plays an important role in the intrinsic pathway; it forms a bridge whereby factor VII can activate factor IX → activate factor X

common pathway:

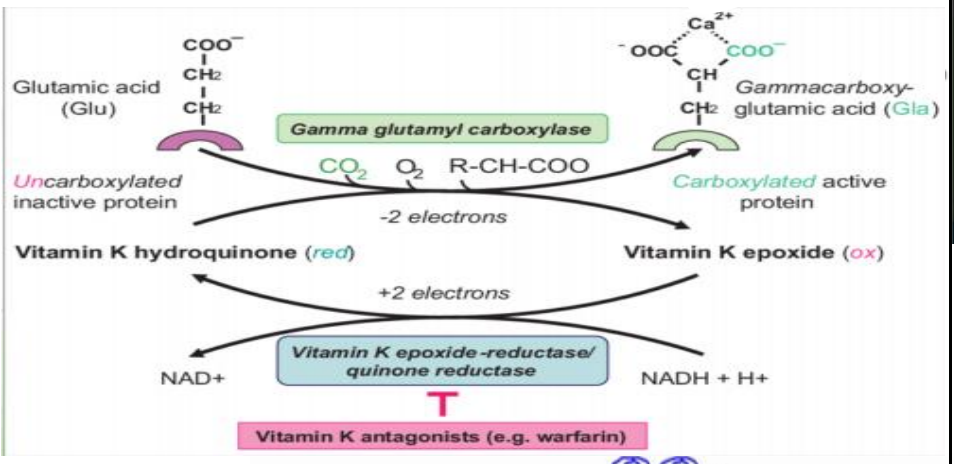
activation of factor X → activation of prothrombin → formation of the fibrin network

notice the involvement of the non-enzymatic protein cofactors, platelet surface and Ca.



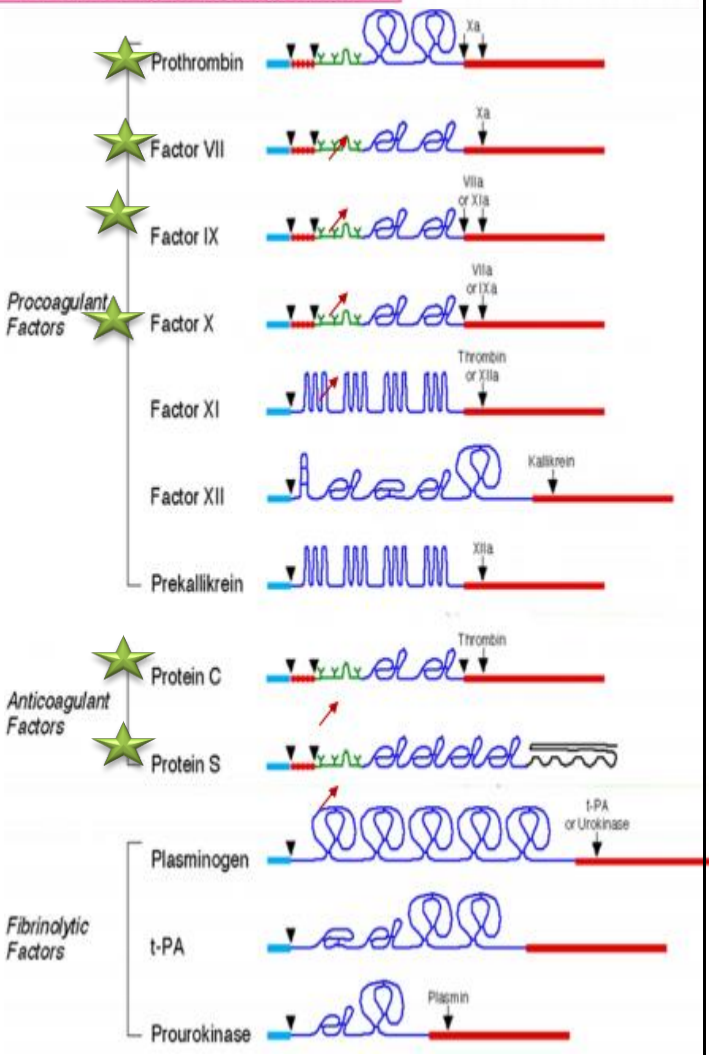
Gla domain:

-> a domain that contains 9-12 glutamate residues and it is part of the primary structure of prothrombin, factors (VII, IX, X), protein C and protein S. It is a substrate for an enzyme known as **carboxylase**.

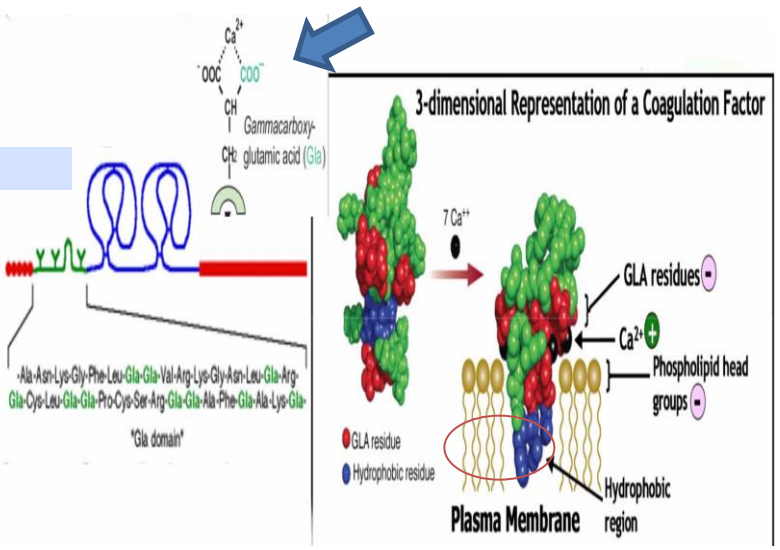


-> An ER/Golgi **carboxylase** binds to prothrombin and factors IX, VII, and X and **converts 10≥ glutamate (Glu) residues** to **γ-carboxyglutamate (Gla)**, by adding another carboxyl group to each Glu.

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

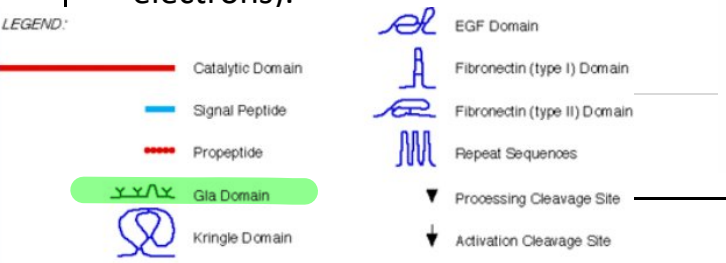


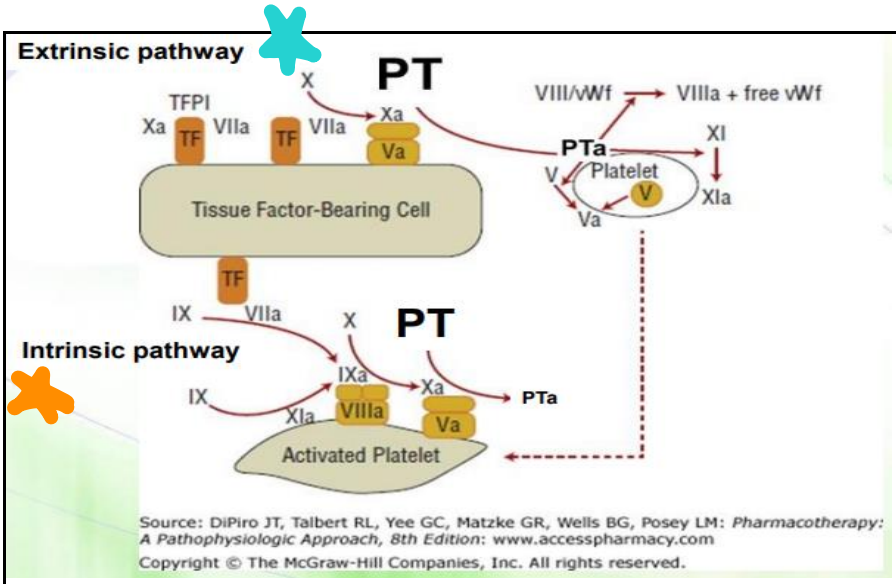
-> notice that this domain is followed by a small (10 amino acid) hydrophobic region which strengthens the interactions between these factors and the plasma membrane of platelets where biochemical processes of coagulation take place.



The role of Vitamin K

Vitamin K participates in conversion of Glu to γ-Gla. (It is needed for carboxylation as a source of electrons).





Vitamin K becomes oxidized to vitamin K epoxide and must be regenerated by an enzyme known as **vitamin K epoxide reductase** and this requires NADH as a source of electrons. This enzyme is the target for vitamin K antagonist (Warfarin).

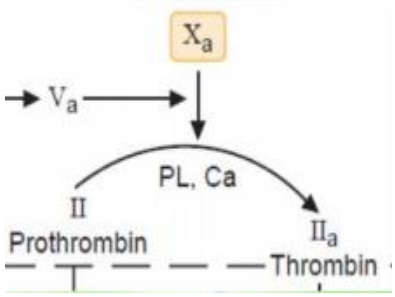
Newborns are at risk for early vitamin K deficiency bleeding. Why? (signs and symptoms: gum bleeding, formation of bruises)

1- The placenta is a poor passage channel for fat-soluble compounds, including vitamin K.
2- Neonates are born with an immature liver that impairs coagulation factor synthesis and GLA modifications.
3- Breast milk is a poor source of vitamin K.
4- Intestinal flora, the main source of vitamin K, is not established yet.

Prothrombin activation

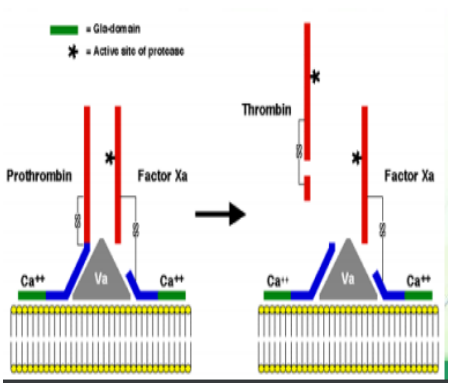
- The complex of factor Xa/Va is the "**prothrombinase complex**". factor V also interacts with prothrombin. (due to interaction with Ca ions) → factor V brings factor X and prothrombin close together.

- **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.



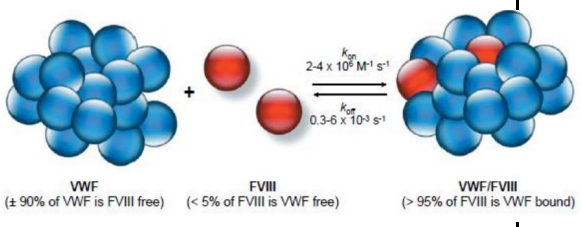
in the extrinsic pathway prior to activation of factor X, you have the activation of factor VII and with the help of TF.

In the intrinsic pathway, you have the involvement of TF which activates factor IX and helps in activation of factor X by activation of factor VIII. (factor VIIIa and factor IXa form complex that activates factor X) ,the complex called "tenase complex".

Factors V and VIII

- The intrinsic tenase complex contains the active factor IX (IXa), its cofactor factor VIII (VIIIa), and Ca2+ .
- The extrinsic tenase complex is made up of tissue factor, factor VIIa, and Ca2+ .
- 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.

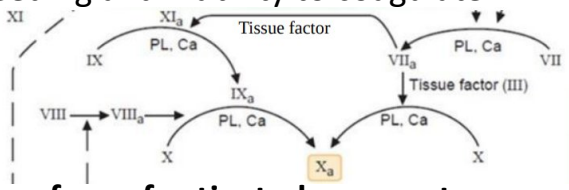


→ Both factors V and VIII are activated by thrombin via a feedback mechanism

→ **Factor VIII** circulates in the plasma bound to **von Willebrand factor**, which increases VIII half-life, and, when released, it gets activated.

vWF is synthesized and secreted by endothelial cells and platelets

→ **<u>von Willebrand factor deficiency</u>** is associated with a decrease in the plasma concentration of factor VIII. [suffer from excessive bleeding and inability to coagulate blood]



Tissue Factor:

integral membrane protein that is expressed on the surface of activated monocytes ,sub- endothelial cells ,and other cells So blood cells and platelets are not exposed to sub endothelial cells unless there is tissue injury then you can have platelets binding to a tissue factor.

Once they interact with tissue factor you can have activation of factor 10 in the extrinsic pathway , while in the intrinsic pathway the tissue factor is also involved whereby it is important in activating factor 9 which activates factor 10 .

The complex of tissue factor and factor 7 is known as "initiation complex" because it activates the extrinsic and the intrinsic pathways . (Tissue factor increases the proteolytic efficiency of VIIa) .

Initiation of the intrinsic pathway

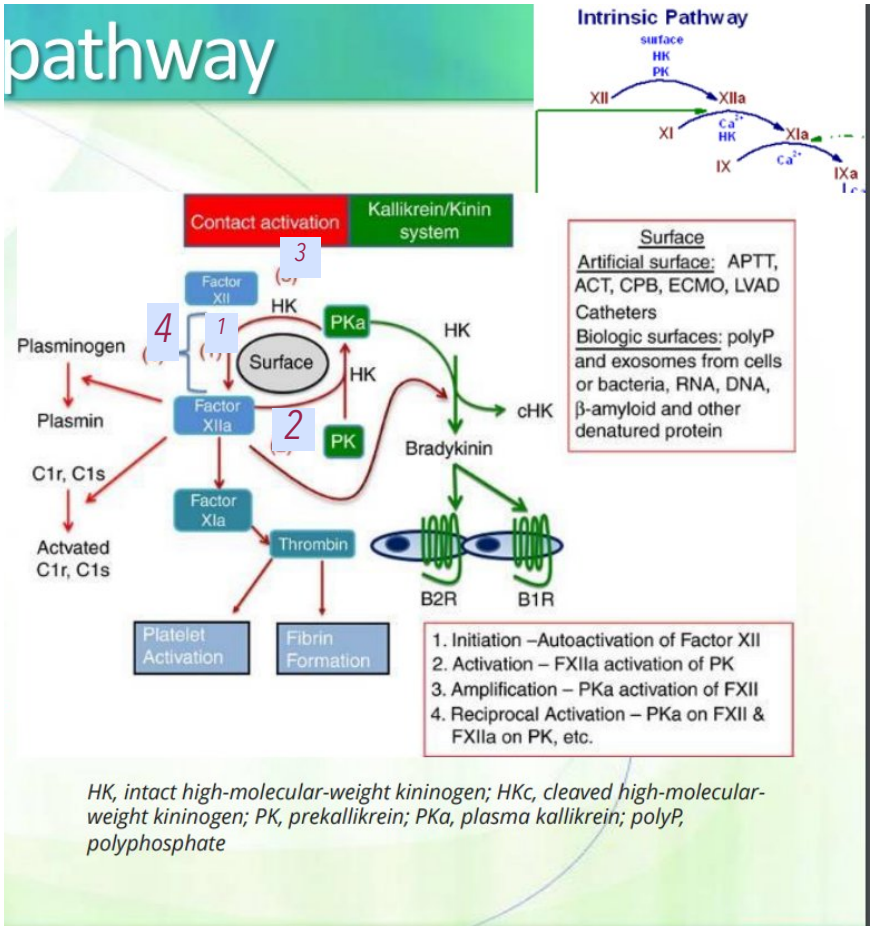
let's look upstream of the intrinsic pathway
the a major player in initiating the intrinsic pathway is factor 12.

Factor XII is autoactivated to XIIa, which has substrates:

1- plasminogen which is cleaved by factor 12 into plasmin and it is involved in fibrinolysis (removal of the fibrin clot). 4
2- the immune response by activating the complement system (we're not going to talk about this)
3- factor 11: once activated by factor 12 it can activate factor 9 which activates factor 10. 1
4- kallikrein - exists in the inactive form known as prekallikrein - prekallikrein is activated by factor 12 and kallikrein can then activate more factor 12. (positive feedback loop) 3
5- a protein known as high molecular weight kininogen cleaved by Factor XII into a peptide known as bradykinin 2

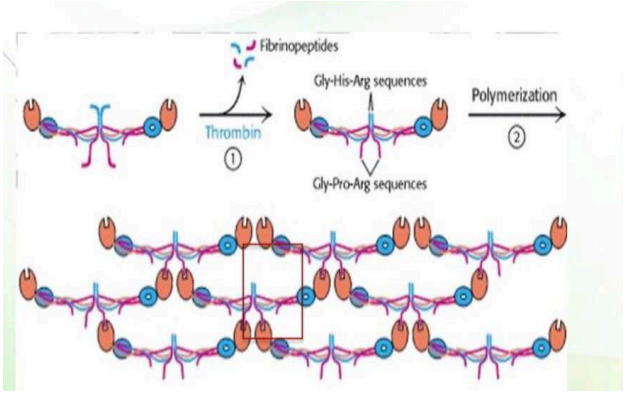
bradykinen can then bind to receptors on the cell surface of different proteins including endothelial cells, muscle cells and it causes vasodilation allowing for accumulation or recruitment of more cells including platelets

Prekallikrein, HMW kininogen, factors XII and XI are exposed to a negatively charged activating surface.



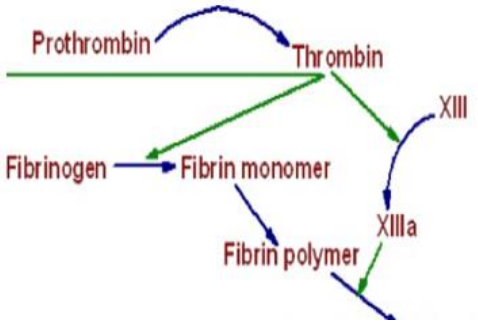
Formation of fibrin clot :

After activation of factor X , it activates prothrombin into thrombin which acts on fibrinogen by converting fibrinogen into fibrin by removing a number of fibrinopeptides and this results in the ability of fibrin molecules to form electrostatic interactions between the head and the tails of two other molecules



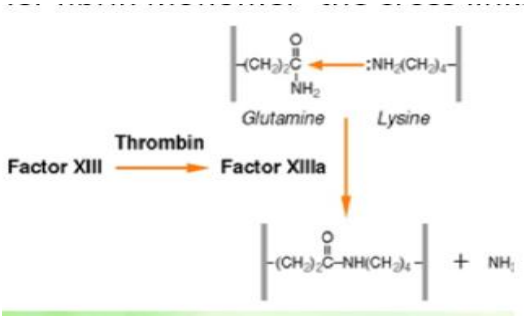
Then there will be aggregation of fibrin molecules together forming a clot known as a soft clot because the interaction between all these molecules is based on electrostatic interactions which is non-covalent.

"Fibrinogen is a two triple-stranded helical protein held together by disulfide bonds."



Factor XIII

It is a transglutaminase activated by thrombin to form covalent (cross linking)between Glu of one fibrin monomer to a Lys on another fibrin monomer , the cross linking strengthen the fibrin mass forming a "hard clot".

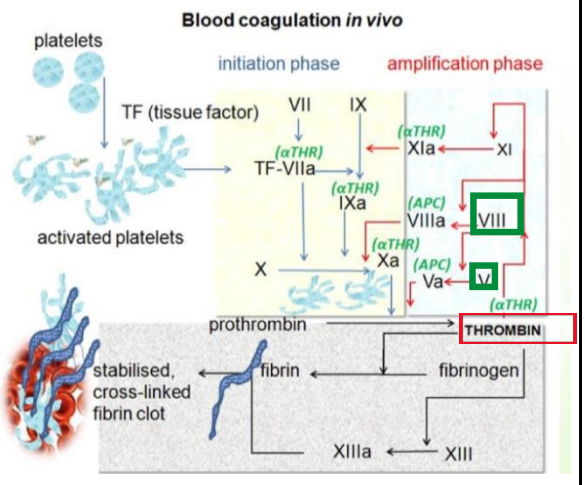


The clot doesn't only contain fibrin network ,it also entraps platelets inside forming a platelet plug.

Amplification of coagulation reactions

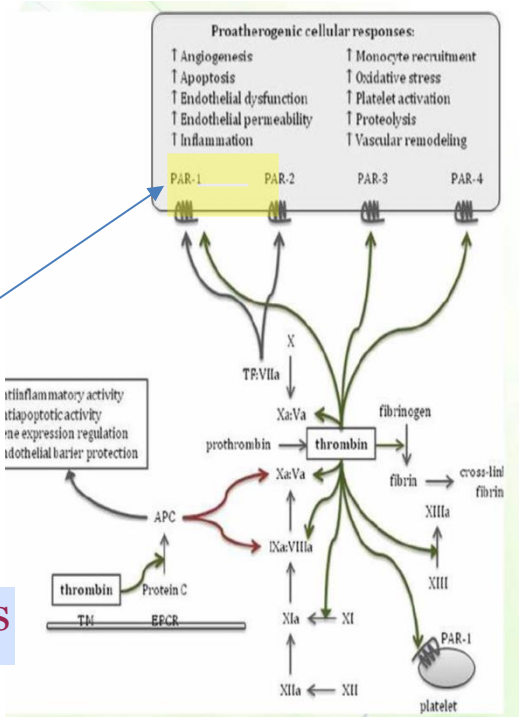
The sequential enzymatic activation allows for amplification.

Amplification also results from positive feedback reactions. The thrombin molecule acts back in all of these factors ,so it activates more factor V ,VIII, VII, XI, that's why you have more amplification of all of these zymogens , {specifically getting to the end factor X that activates more and more prothrombin to thrombin.}



Rules of thrombin

1. Recruiting platelets to the site of injury
2. Amplification of the coagulation complex
3. Formation of soft clot (proteolytic cleavage of fibrinogen) where fibrin monomers form a complex.
4. Attenuation of its own activity (activation of protein c) …. It terminates the coagulation.
5. Formation of hard clot by (activation of factor XIII)
6. Other actions: binding to its receptor (protease activated receptors) on the surface of platelets and endothelial cells induces vascular remodeling (e.g. angiogenesis) and inflammation.



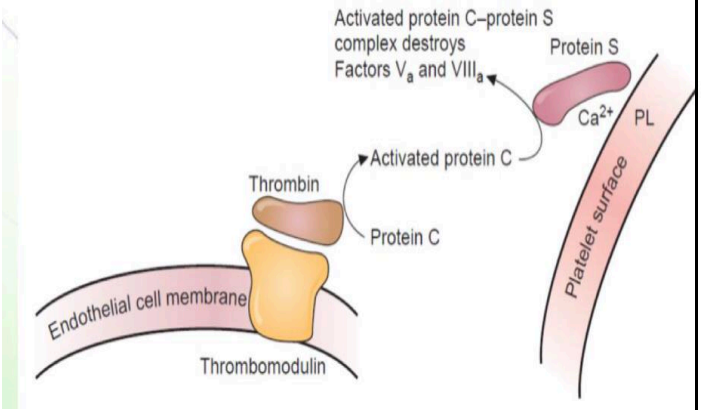
Anti-clotting factors

1. Protein C and protein S

Thrombin binds to a protein known as thrombomodulin in the surface of endothelial cells

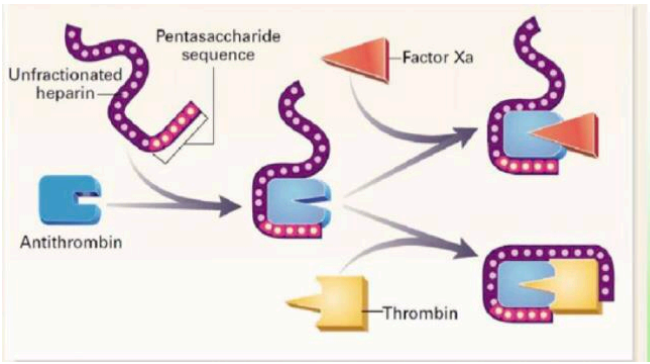
Thrombin can then activates protein C which forms a complex with protein S ,{both of which are vitamin k dependent co- factors}

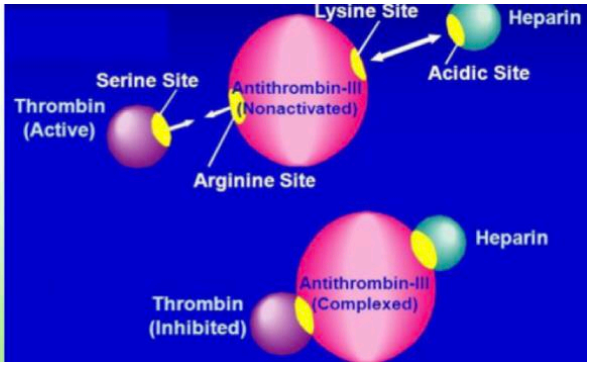
The complex degrades factors V and VIII, so we have termination of activation of prothrombin and activation of factor 10.



2. Antithrombin III

Serine protease inhibitor of thrombin as well as other clotting factors (IXa,Xa,XIa,XIIa) and Antithrombin binds to heparin sulfate (polysaccharide synthesized by mast cells and





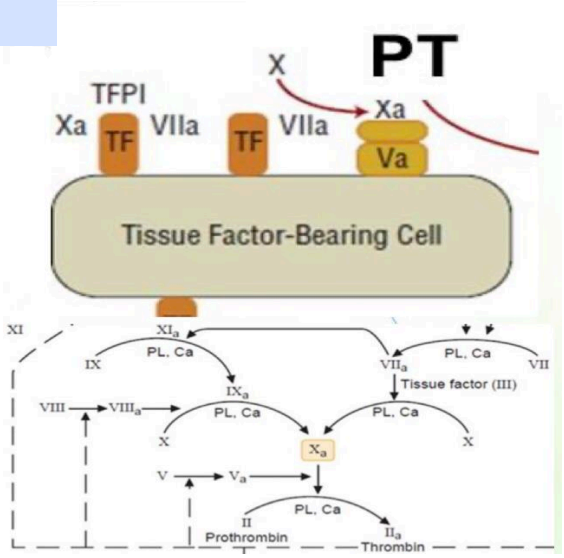
VIIIx when complexed with TF

present on surface of endothelial cells) this binding changes the conformation of antithrombin III promoting binding to its substrates.

in order for antithrombin 3 to function it has to bind to heparin (a glycose aminoglycan) so the the positively charged amino acid lysine residues of antithrombin 3 would interact with the acidic site of heparin the structure of antithrombin 3 can then it changes allowing it to bind to thrombin and inactivating it

*in the clinic phlebotomy tubes are often treated with heparin in order to inhibit clot formation

Tissue factor pathway inhibitor



It is a protein found in plasma lipoproteins and bound to the vascular endothelium.

*function: 1-It binds to and inhibits factor Xa.

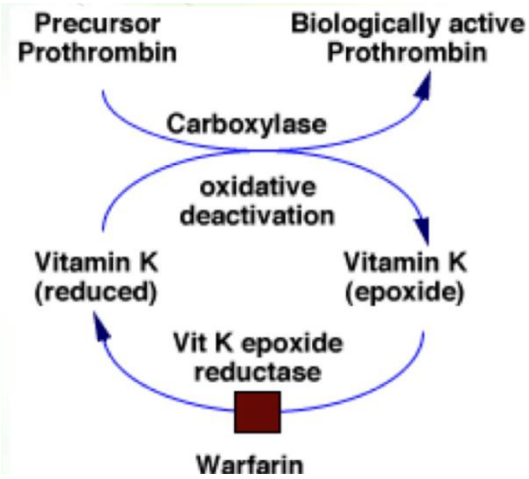
2-The Xa-TFPI complex then interacts with tissue factor-VIIa complex and inhibits its activation of factors X and IX.

3-Protein S binds to TFPI localizing it to membrane surfaces and enhancing the inhibition of Xa.

4-TFPI is also able to inhibit Xa-activated Va resulting in inhibition of the pro-thrombinase complex.

Anticoagulants

Blood clotting can be prevented by addition of Ca+2 chelators and vitamin K antagonist such as warfarin which inhibits reduction of vit K and synthesis of active prothrombin and factors VII, IX,X.



Warfarin inhibit the regeneration of the reduced form of Vit k

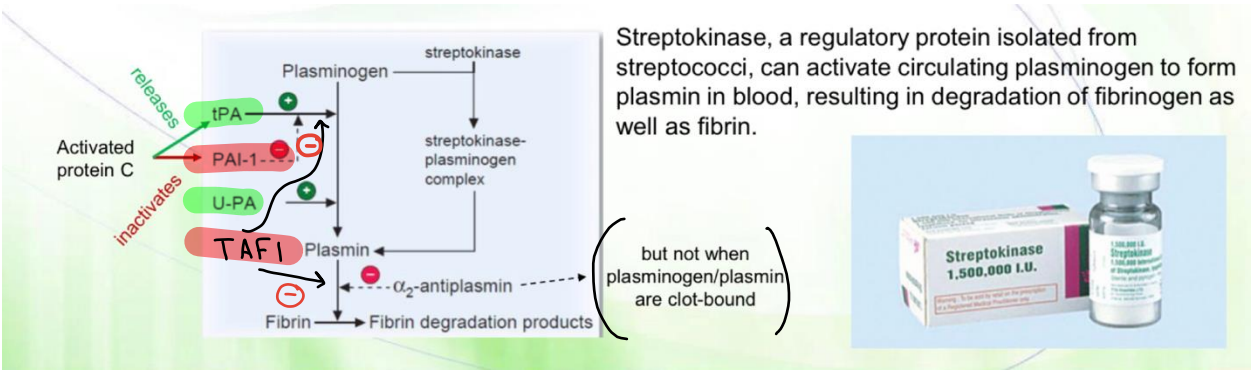
Degradation of the fibrin clot

It is important to prevent clot formation when it's not needed by anti-clotting factors to dissolve a clot when formed , clot dissolution starts concomitant with its formation

The fibrinolytic system

Plasmin a serine protease formed from plasminogen , it is responsible for fibrinolysis where it catalyzes the hydrolysis of fibrin and fibrinogen to degradation products

- Plasminogen has a high affinity for fibrin clot



The role of Urokinase

Urokinase, a serine protease is formed from the zymogen pro-urokinase, It is a potent plasminogen activator, and used clinically.

that ensures the removal of the clot without affecting the surrounding tissue

there are two activators for plasminogen
1- tissue plasminogen activator
2- urokinase type plasminogen activator
they cleave the n-terminal portion of plasminogen activating it

these two are also regulated by inhibitors

1. plasminogen activator inhibitor :
targets both the plasminogen activator tissue type and urokinase type

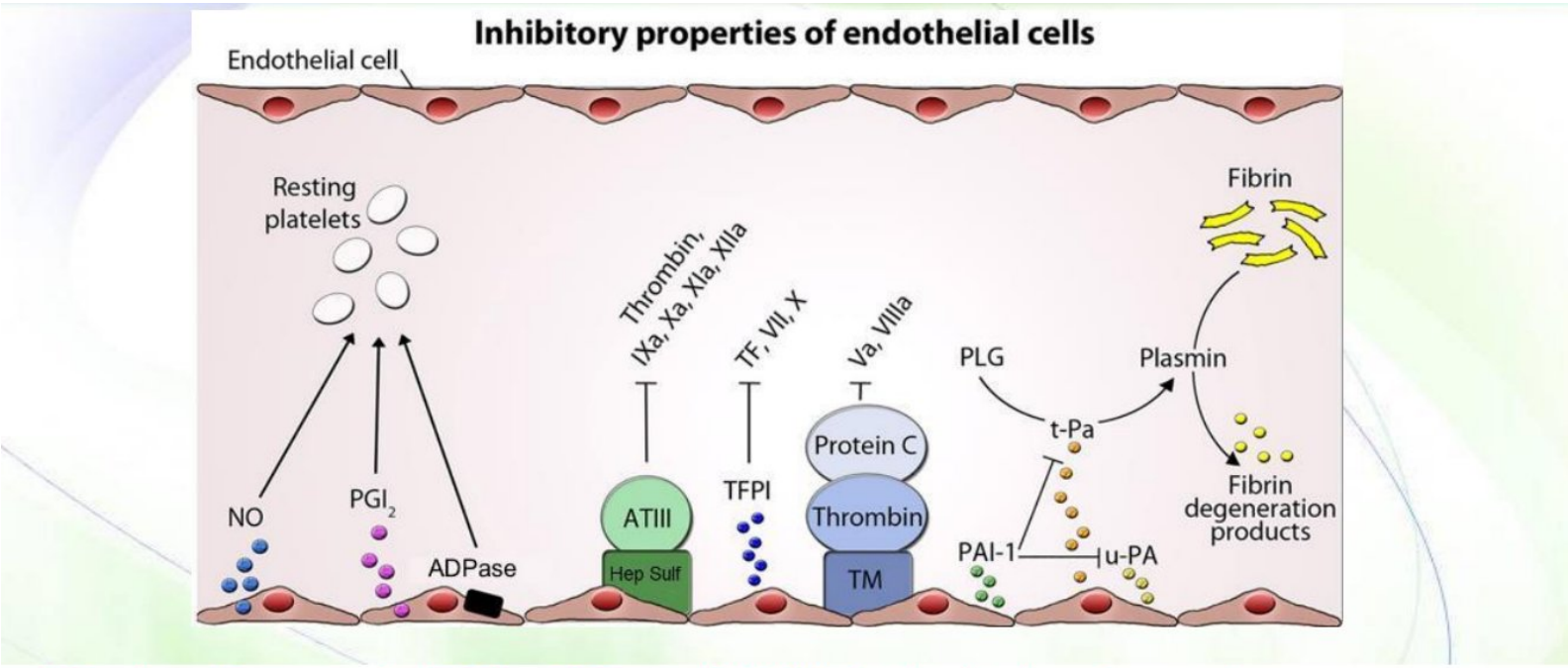
2. thrombin activatable fibrinolysis inhibitor or TAFI
removes the n-terminal lysine residues in fibrin (why are these lysine residues important? because this is how plasmin bind to the fibrin clot)

Thrombin activatable fibrinolysis inhibitor (TAFI) is a carboxypeptidase that removes terminal lysine residues and prevent fibrinlysis

now plasmin cannot bind to fibrin and it gets released and inhibited right away by alpha2 antiplasmin

activated protein c can also activate tissue plasminogen activator by releasing it and at the same time inhibits the inhibition of this enzyme which is called PAI-1 (Plasminogen activator inhibitor-1).
So Activated protein C is an inducer of fibrynolysis

Role of endothelial cells in coagulation



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

is thrombin the maestro?

it could be endothelial cells, because they play a very important role in blood coagulation

1- release nitric oxide (a vasodilator), prostcyclin and ADP (inhibit platelet adhesion, aggregation and prevent the formation of clots)

2- heparin sulfate on the cell surface (binds to antithrombin 3)

3- tissue factor pathway inhibitor which inhibits the tissue factor as well as factors 10 and 7.

4- thrombomodulin is another molecule that exists on the surface of endothelial cells (binds to thrombin which binds to protein c and protein c inhibits factors five and eight by degrading them)

5- prevent accumulation of the fibrin clot and induce its lysis by releasing plasminogen activators tPA and UPA as well as their inhibitor so they balance out the the fibrin formation clot formation and lysis

it's really a symphony it starts slow and then the music goes up and then it slows down at the end
so listen to vivaldi four seasons as you're studying this lecture and connect the music to the biological process

Enjoy ✨