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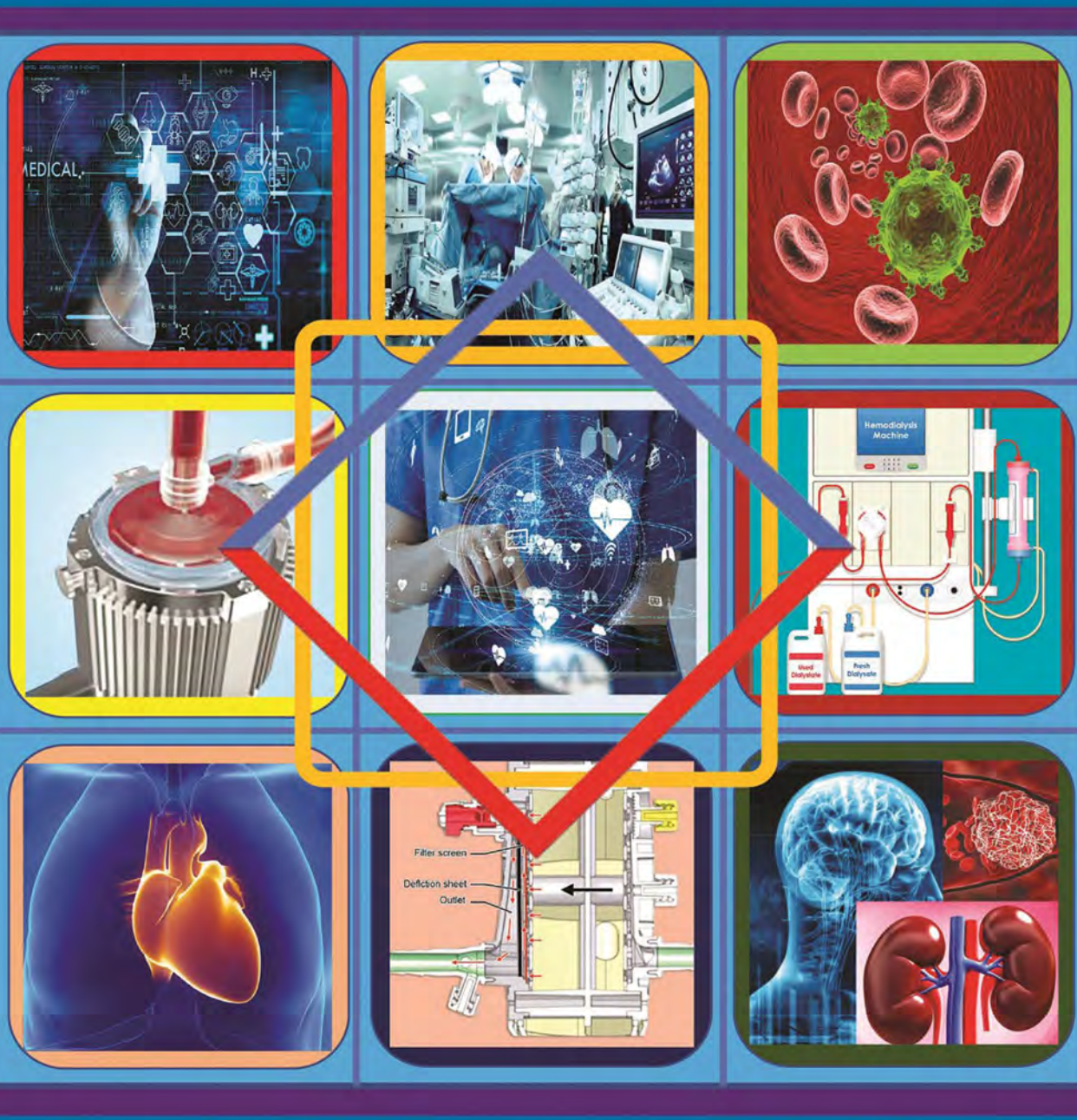
ECMO
PRACTICAL MANUAL

A Stepwise Approach



Pranay Oza
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Foreword
BK Rao

3rd Edition

JAYPEE

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7
CHAPTER

Protocol for Anticoagulation

GOAL FOR ANTICOAGULATION

Anticoagulation reduces thrombin activity and fibrin formation to decrease thrombotic events without causing bleeding.

ANTICOAGULANT

The ideal anticoagulant is:

- Prevent unwanted thrombus formation
- Allow clot formation when necessary
- Predictable effects
- Easily measurable effects
- Short half-life
- Easily reversible.

There is no ideal coagulant so far available, at present the one which is very close to ideal anticoagulant is heparin. Heparin remains the most preferred anticoagulant during an extracorporeal membrane oxygenation (ECMO) run. Other alternative anticoagulants which are used in India are thrombin inhibitors such as bivalirudin and argatroban.

HEPARIN

- Its principal effect is on intrinsic pathway.
- It acts via antithrombin III (AT III) and it binds with AT III to accelerate the inhibition of thrombin thousandfold and thereby decreases the tendency to form clots.
- It forms complexes with activated factors IXa, Xa, XIa, and XII and inhibits them (intrinsic pathway) and thereby prevents activation of prothrombin to thrombin.
- The effect is seen almost immediately and the half-life is dose-dependent. For the ECMO application it is around 45–70 minutes.
- Heparin requirement will defer from patient to patient and in same patient from time to time. The effect of heparinization will depend on many factors.
- It is removed from circulation by the reticulo-endothelial (RE) system.
- It is inactivated in the liver by heparinase and products are excreted in urine.

Protocol for Heparinization

- *Heparin bolus should be given as soon as:*
  - *Seldinger and semi-Seldinger technique:* The vascular puncture done and guide wire is in situ.
  - *Open technique:* Should be given once the vessel is exposed and before opening the vessels.
- *Dosage:*
  - *Bolus dose:*
    - Heparin should be 50–75 units/kg, but depends on many factors.
    - *Bolus dose should be decreased:*
      - *Some coagulopathy:* Elevated international normalized ratio (INR), disseminated intravascular coagulation (DIC), hepatic dysfunction
      - Thrombocytopenia
      - Underwent recent surgery
      - Polytrauma with head injury
      - Recent thrombolysis
    - If the patient is not on ECMO within 30 minutes after initial bolus doses, a new activated clotting time (ACT) needs to be taken as a check. If the ACT is <200 seconds, an extra bolus of 10–20 IU/kg of heparin needs to be given.
  - *Maintenance dose:* Should be started with 7.5–20 units/kg/min; do ACT after 30 minutes of heparin and depending on the ACT start with maintenance dose of heparin.
- *Titration of heparin dose:*
  - ACT levels should be maintained.
    - For venovenous (VV) ECMO around 160–180 seconds
    - For venoarterial (VA) ECMO around 180–200 seconds

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- In case of bleeding ACT can be kept at 140–160 seconds
- If patient is prothrombotic then around 180–200 seconds
- Repeat ACT 4 hourly and if unstable then repeat every 1 hourly for adults.

- *Activated partial thromboplastin time (aPTT) levels:* Can be alternatively monitored instead of ACT and its level should be maintained around one and a half to two times of control so usually between 50 and 70.
- In case of any discrepancy in partial thromboplastin time (PTT) and ACT values, follow:
  - Anti-Xa
  - R value of thromboelastogram (TEG)
  - aPTT

- Heparin titration as per ACT and/or aPTT level is described in **Table 1**.
- *Heparin dose needs to be modified:*
  - *Patient actively bleeding:* Reduce ACT to 140–160 seconds.
  - *Thrombocytopenia:* If platelets are <50,000 then reduce the dose. In this case PTT will be a better guide.
  - *Patient planned for surgical intervention:* Reduce ACT to 140–160 seconds.
  - During platelet and clotting factor [fresh frozen plasma (FFP) and cryoprecipitate] transfusion give extra bolus of heparin and check ACT after 30 minutes.
  - *Decreased heparin excretion:*
    - *Liver disease:* Vitamin K deficiency
    - Renal disease
  - During weaning of the patient from VA ECMO and consequently lower flows, the ACT may have to be adjusted in order to avoid clot formation, usual target is around 200.
  - During the standby period of the ECMO system, both the circuit ACT and the patient's ACT values must be monitored.

Heparin-induced Thrombotic Thrombocytopenia

- Incidence is low and is around 0.2–5% and is seen mainly in adults.
- Characterized by multiple white arterial thrombi and platelet count <10,000, typically occurs 5–10 days of starting heparin. Platelet counts remain <10,000 even after platelet transfusions.
- Determines if the heparin-platelet factor 4 (PF4) antibody is present but high false positive rate.
- Sensitivity is 95%, specificity is 90% but only if the pretest probability is high.
- Must stop heparin
- Start alternative anticoagulation: Argatroban, bivalirudin.

Heparin Resistance

- ACT/aPTT does not increase even after increasing heparin dose to nearly double.
- Decreased AT III level
- Extreme thrombocytosis
- Increased clearance: Increased urine output
- Increased acute phase reactants, e.g., fibrinogen and factor VIII, in neonates usually factor VIII level is elevated.
- *Management:*
  - Treat underlying cause
  - Increase heparin infusion, can go up to 40 units/kg/min
  - AT III concentrate or FFP transfusion.

ALTERNATIVE ANTICOAGULANT

- *Low-molecular-weight heparin (LMWH) (dalteparin, enoxaparin):*
  - Fewer side effects, more predictable anticoagulation
  - More difficult to monitor (anti-Xa); not reversible with protamine.
  - No recommendation of using during ECMO run

TABLE 1: Heparin dose titration chart.

aPTT level	*ACT level*	*Heparin bolus*	*Discontinue drip (in minutes)*	*Infusion*
<40	<140	20 unit/kg	–	Increase by 40% dose
40–50	140–159	10 unit/kg	–	Increase by 20% dose
55–80	160–190		–	
81–90	191–210		–	Decrease by 30% dose
91–115	211–240		For 30 minutes	Decrease by 50% dose
116–150	241–280		For 60 minutes	Decrease by 50% dose
>150	>280		Discontinue and repeat ACT after 1 hour, investigate for high levels	Restart after levels decrease and cause established

(ACT: activated clotting time; aPTT: activated partial thromboplastin time)

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- *Heparinoids (danaparoid):*
  - Fewer side effects—no heparin-induced thrombocytopenia (HIT)
  - Expensive; anti-Xa monitoring; not reversible
  - No recommendation of using during ECMO run
- *Direct thrombin inhibitors (DTIs):* Bivalirudin, argatroban, lepirudin, dabigatran)
  - They bind directly to thrombin and do not need antithrombin or any other plasma protein.
  - New, expensive, relatively little experience
  - aPTT, ACT monitoring
  - No specific antidotes
  - Can be reversed by factor VIIa
- Coated circuits with nitric oxide (NO), experiments are going on.

Argatroban

- It is another anticoagulant that can be used instead of conventional heparin.
- It is a direct competitive inhibitor of thrombin and inhibits both free and clot-bound thrombin.
- *Dose:* Loading dose is 100–150 μg/kg given over 3–5 minutes, 30 minutes before initiation of ECMO. While maintenancedose is 1–2 μg/kg/min, and to be started immediately after the bolus dose.
- *Metabolism:* It is metabolized in liver and primarily excreted in feces.
- Half-life is 60–90 minutes in adults and 35–75 in pediatrics.
- Its effect can be assessed by ACT and PTT. PTT is more relied for adjusting the dose of argatroban.
- PTT should be maintained at 50–70 seconds (1.5–2 times the control)
- *Advantages:*
  - It acts directly on thrombin so its effect is independent of AT III
  - It does not cause thrombocytopenia.
- *Disadvantages:*
  - There is no commercially available reversal agent.
  - Hepatic dysfunction can increase time of clearance.
- *Dose adjustment:*
  - If PTT is >80 then decrease infusion by 20%.
  - If PTT is <50 then increase the infusion by 20%.
  - Wait for 2 hours, after making any change to see desired effect.
  - Recheck PTT every 2 hourly till PTT stabilizes to desired range.

Bivalirudin

- It is the second-best anticoagulant used in India.
- It is a direct thrombin, inhibitor, so they do not require AT III for it is effect.
- It has a half-life of approximately 25 minutes in adults and 15–42 minutes in pediatric.
- It is partially eliminated by the kidney and mostly metabolized by proteolytic enzymes.
- The dose of bivalirudin is 0.5 mg/kg bolus followed by 0.05–0.5 mg/kg/h.
- It is monitored by doing PTT. The target aPTT is 50–70 seconds (1.5–2 times the control).
- There is more tendency of clot formation in low-flow states, e.g., in cardiac stunning and in low-flow areas in circuit like connectors.
- It can be quickly removed by continuous renal replacement therapy (CRRT) or plasmapheresis.
- No risk of HIT or heparin resistance.

Recombinant Hirudin

- Not been used for ECMO
- Has a plasma half-life of 40 and 120 minutes after intravenous and subcutaneous administration, respectively.
- The dose is monitored and adjusted to give an aPTT ratio of 1.5–2.5, as above this range there is an increased risk of bleeding.
- Clearance of hirudin is mostly renal.

MONITORING OF ANTICOAGULATION

The most common method of monitoring anticoagulation is by ACT level, but using ACT alone to guide anticoagulation may not be optimal. The heparin effect can be accurately monitored by anti-Xa levels. It is the overall net effect of thrombin and fibrin formation reduction with heparinization that is clinically important, not the amount of inhibition of factor Xa or direct heparin effect. There are limitations with each test and hence, a combination of tests is required for optimal anticoagulation management. So, it is important to examine the hemostatic system holistically with multiple laboratory tests that are interpreted in the context of the patient and ECMO circuit conditions.

Activated Clotting Time Level

- It can be used for monitoring anticoagulation only if heparin is used.
- *It should be done:*
  - Before initiation if patient is on heparin or has coagulopathy
  - After 30 minutes to 1 hour of initiation of ECMO
  - Every 4 hourly if ACT is stable after starting heparin drip
  - Every 1 or 2 hourly if ACT is unstable

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TABLE 2: Elevated activated clotting time—causes and management.

Causes	*Management*
Excessive heparin dose	Titrate heparin **(Table 1)**
Underlying liver or renal disorder	Decrease heparin dosage, transfuse FFP if INR < 2
Hypothermia	Check heater unit, slowly correct temperature
Thrombocytopenia	Decrease heparin, transfuse platelets if required
Hemodilution	Correct the cause
Disseminated intravascular coagulation (DIC)	Do TEG, replace clotting factor, evaluate circuit-induced versus sepsis-induced DIC
Clotting factor deficiency	Do TEG, replace clotting factor

(FFP: fresh frozen plasma; INR: international normalized ratio; TEG: thromboelastogram)

TABLE 3: Decreased activated clotting time—causes and management.

Causes	*Management*
Heparin dose is inadequate	Check preparation, titrate heparin **(Table 1)**
Increased clearance—increased urine output	Increase heparin, evaluate diuresis
Platelet or fresh frozen plasma (FFP) or cryoprecipitate transfusion	Give additional bolus dose
Low antithrombin III level (heparin resistance)	Transfuse FFP or keep high dose of heparin or switch over to bivalirudin

- *SOS:*
  - Any procedure is required to be done
  - If there is bleeding
  - If there is clotting seen in the system
  - 30 minutes after blood product transfusion (platelet or FFP or cryoprecipitate)
- *Normal range:* 90–110 seconds
- The level to be maintained at 160–200 seconds
- *Factors affecting ACT levels:*
  - Platelet number and function
  - Fibrinogen level
  - Deficiency of coagulation factor
  - Temperature
  - Hemodilution
  - *Technical factors:* Different ACT machines yield different results, so results from two different ACT machines are not interchangeable.
- *Elevated levels:*
  - Check calibration and technical issues.
  - Evaluate the cause and treat **(Table 2)**.
  - Decrease heparin drip or even stop heparin drip for transient time if it is too high.
  - Repeat ACT every 1 or 2 hourly till it gets stabilized.
- *Decreased levels:*
  - Check calibration and technical issues.
  - Evaluate the cause and treat the cause **(Table 3)**.
  - Give some bolus heparin and at the same time increase the heparin drip.
  - Repeat ACT every 1 or 2 hourly till it gets stabilized.

Activated Partial Thromboplastin Time Level

- It can be used as monitoring anticoagulation for both heparin and DTIs.
- *It should be done:*
  - 4 hourly if it is the only parameter used for anticoagulation monitoring (ACT not available)
  - Once a day or as and when required if not used as primary parameter for anticoagulation monitoring
- Level to be maintained at ~1.5–2.5 times the control between 50 and 70 seconds
- *Elevated levels:*
  - Evaluate the cause and treat.
  - Decrease or stop anticoagulation for transient time if it is too high.
  - Repeat aPTT every 1 or 2 hourly till it gets stabilized.

Prothrombin Time with International Normalized Ratio

- *It should be done:*
  - Once in 3 days
  - Whenever ACT and PTT are high, to rule out associated hepatic dysfunction
- PT with INR is usually not affected by heparin.
- It evaluates factor VII (primarily) and II, V, and X.
- *Elevated levels:*
  - *Causes for the:*
    - Vitamin K deficiency
    - Liver disease
    - DIC
  - *Treatment for elevated levels:*
    - Correction required if INR is >2
    - FFP transfusion
    - Injection vitamin K.

Antithrombin III Level

- Not frequently done and available in India
- *It should be done:*
  - Ideally once in 3–5 days
  - Whenever heparin requirement increases

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- *Normal range:* 120
- The level to be maintained at >70%
- It is considered to be the most important inhibitor in coagulation cascade.
- It is required for the action of heparin.
- *Causes for decreased levels:*
  - Neonates have developmentally low antithrombin levels
  - DIC
  - Microangiopathic hemolytic anemia [hemolytic–uremic syndrome (HUS)]
  - Veno-occlusive disease
  - Chronic liver disease
  - Protein loss (ascites or nephritic syndrome)
  - Hemodilution effect especially in children; adults are less affected by dilution phenomena.
- *Effect of decreased levels:*
  - Low heparinization so heparin requirement increases
  - Clotting tendency due to inadequate heparinization
- *Treatment for decreased levels:*
  - Replace AT III when the level falls <70%, but AT III concentrates are not available in India hence, we have to give FFP transfusion which has AT III
  - Dose = [desired level (120) – measured level] × weight in kg/1.4.

Anti-factor Xa

- It should be done ideally, once daily.
- *Normal range:* 0.3–0.7 U/mL
- The level to be maintained at >0.3
- It is used to measure plasma level of heparin. It is a more specific method of monitoring unfractionated heparin, but does not provide information on the overall functional effect of thrombin and fibrin formation.
- It cannot be used to monitor direct thrombin inhibitors.
- It is not affected by fibrin, fibrinogen, and fibrin degradation products (FDPs).
- *It is not reliable in:*
  - Hyperbilirubinemia
  - Hypertriglyceridemic
  - Increased plasma-free hemoglobin
- Not a commonly used test in present scenario, as it is costly and not available widely.

Viscoelastic Hemostatic Assays

- *It allows the assessment of:*
  - *Clot initiation:* Clotting time
  - *Clot strength or amplitude:* Fibrinogen and platelet contribution
  - *Clot stability:* Fibrinolysis



Fig. 1: Thromboelastogram machine.



Fig. 2: Rotational thromboelastometry Delta.

- It is used as a guide for administration of blood products.
- *Two devices:*
  - TEG **(Fig. 1)**
  - Rotational thromboelastometry (ROTEM) **(Fig. 2)**.

THROMBOELASTOGRAM

- It should be done ideally every day or whenever bleeding
- It guides the component replacement required and decreases blood product usage in case of bleeding during ECMO.
- It shows the net effect of hemostatic components on blood clotting mechanism.
- Gives us dynamic information on all aspects of conventional coagulation monitoring.
  - Clot formation
  - Clot kinetics
  - Clot strength and stability
  - Clot resolution

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TABLE 4: Thromboelastography interpretation.

Parameters	*Normal range*	*Interpretation*	*Elevated causes*	*Decreased causes*
R time	5–7 minutes	Time taken from start of test to initial fibrin formation	• Factor deficiency • Anticoagulation • Severe hypofibrinogenemia • Severe thrombocytopenia	Hypercoagulability syndromes
K	1–3 minutes	Time taken to achieve a certain level of clot strength	• Factor deficiency • Thrombocytopenia • Thrombocytopathy • Hypofibrinogenemia	Hypercoagulability syndromes
Alpha angle	53–67	Measures the rapidity of fibrin build-up and cross-linking (clot strengthening)	Hypercoagulable state	• Hypofibrinogenemia • Thrombocytopenia
Maximum amplitude	59–68	Strength of fibrin clot and platelet function	Hypercoagulable state	• Thrombocytopenia • Thrombocytopathy • Hypofibrinogenemia
Lysis 30 (LY 30)	<7.5%	Gives measure of degree of fibrinolysis	Fibrinolysis	
Coagulation index	–3–+3	Differentiate between primary and secondary fibrinolysis along with lysis 30		

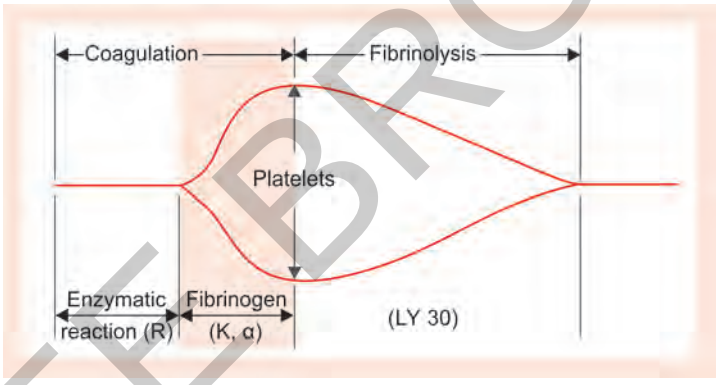

Fig. 3: Thromboelastogram schematic presentation. (LY 30: lysis 30)

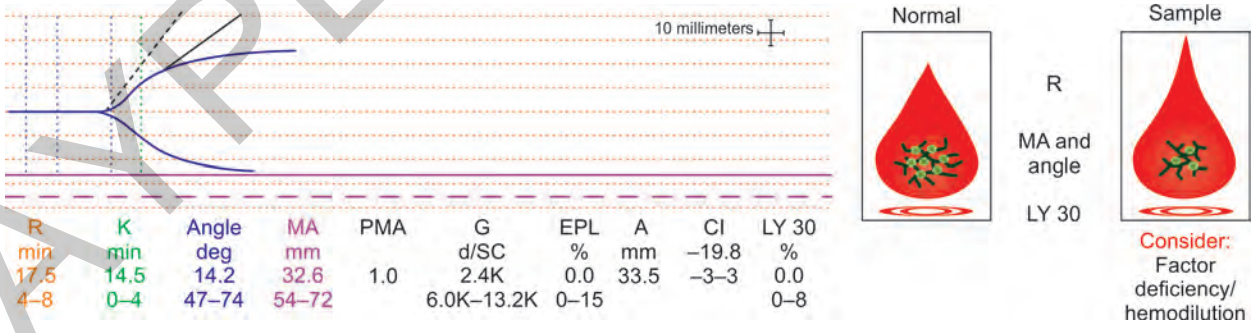

Fig. 4: Thromboelastogram—factor deficiency or hemodilution. (CI: coagulation index; EPL: estimated percentage of lysis; LY 30: lysis 30; MA: maximum amplitude)

- It measures the degree of hypercoagulability and the effects of antiplatelet drug therapy on platelet function.
- Interpretation of TEG **(Table 4)** and normal **(Fig. 3)** and various abnormal TEGs is described in **(Figs. 4 to 7)**

Rotational Thromboelastometry

- This is an enhancement of the traditional thromboelastography method, developed during 1995–1997.

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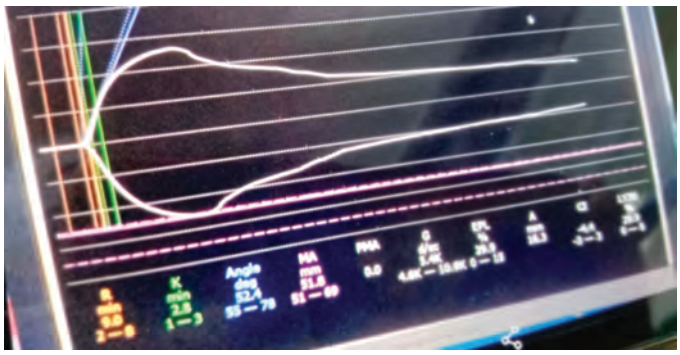

Fig. 5: Thromboelastogram—primary fibrinolysis.

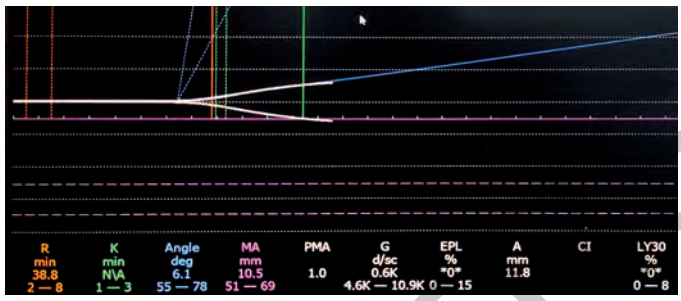

Fig. 6: Thromboelastogram—severe coagulopathy. (CI: coagulation index; EPL: estimated percentage of lysis; LY 30: lysis 30; MA: maximum amplitude)

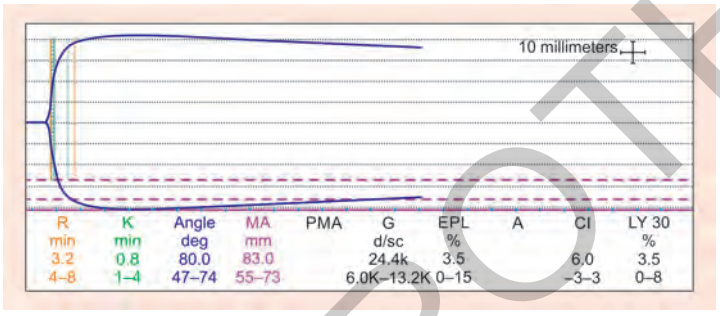

Fig. 7: Thromboelastogram—hypercoagulable state. (CI: coagulation index; EPL: estimated percentage of lysis; LY 30: lysis 30; MA: maximum amplitude)

TABLE 5: Types of rotational thromboelastometry tests and their significances.

Test	*Reagent used*	*Significance*
EXTEM	Tissue thromboplastin (tissue factor)	Clot formation can be assessed within 10 minutes. Assessment of factors VII, X, V, II, and I, platelets, fibrinolysis
INTEM	Activated via the contact phase	Assessment of factors XII, XI, IX, VIII, X, V, II, and I, platelets, fibrinolysis, and for the presence of heparin
FIBTEM	EXTEM + Cytochalasin D	Fibrin formation and fibrin polymerization
APTEM	EXTEM + Aprotinin or tranexamic acid	A better clot formation in APTEM as compared to EXTEM is a sign of hyperfibrinolysis. Also, APTEM estimates if an antifibrinolytic therapy alone is enough
HEPTEM	INTEM + Heparinase	Neutralizes heparin effect and thereby differentiates clotting deficiency versus heparin effect

- Measures the interactions of coagulation factors, inhibitors, and cellular components during the phases of clotting and subsequent lysis over time.
- It is an integrated system, more resistant to vibration with automatic pipetting.
- It gives test data in 15 minutes.
- It uses various activators or inhibitors that are added to the sample, in order to represent different processes of hemostasis **(Table 5)**.
- Normal ROTEM graph with different parameters is described in **Figure 8** and interpretation of all parameters is described in **Table 6**.

Sonoclot

- Sonoclot analysis is a point-of-care test to monitor the coagulation process **(Figs. 9 to 11)**, presenting a comprehensive evaluation of the clot formation and retraction as well as platelet function.
- It measures ACT, clot rate, and platelet function **(Table 7)** and qualitative analysis of curve.
- Heparin effects can be seen by prolonged initial clot formation (ACT) and by slowed fibrinogen to fibrin reaction (clot rate).

Signature curve of sonoclots in different conditions is shown in **Figures 12 to 17**.

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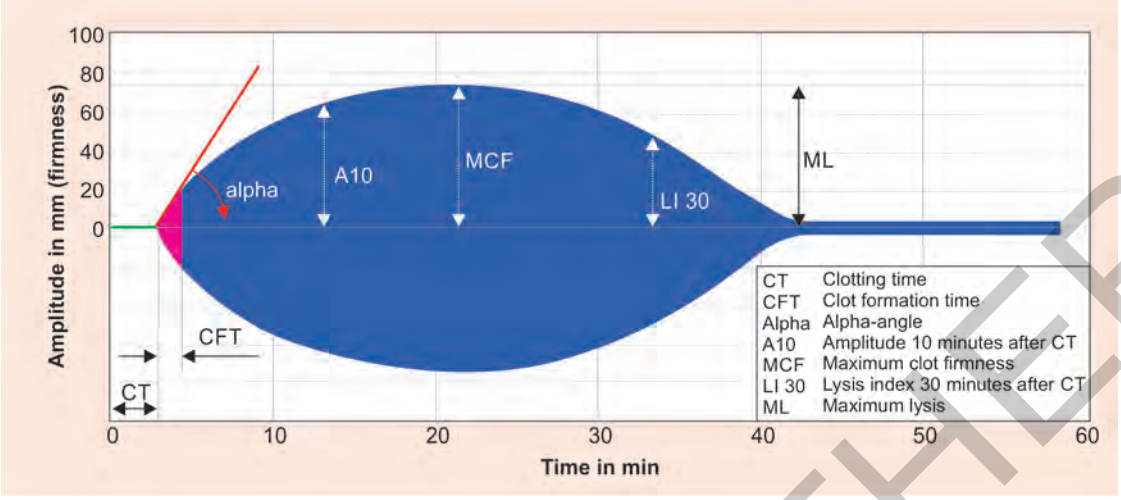

Fig. 8: Rotational thromboelastometry parameters.

TABLE 6: Rotational thromboelastometry parameters interpretations.

	Normal range			
Parameters	***EXTEM C***	***INTEM C***	***FIBTEM C***	***Interpretation***
Clotting time (CT) (seconds)	50–80	161–204		Time from start until initiation of clotting
Clot formation time (CFT) (seconds)	46–149	62–130		Time from initiation of clotting until a clot firmness of 20 mm is detected, usually level >220 is associated with bleeding risk
Amplitude 10 minutes after CT (mm)	43–63	43–62	6–21	• Hypofibrinogenemia • Thrombocytopenia
Maximum clot firmness (MCF) (mm)	55–72	51–69	6–21	Increasing stabilization of the clot by the polymerized fibrin, decreased level increases the bleeding risk
Lysis index 60 minutes after CT (LI 60)	≥94	≥87	≥89	Lysis of clot in <40 minutes carries high risk of bleeding
Maximum lysis (ML)	<15%			Percentage of clot lost in relation to MCF, hyperfibrinolysis (>15% within 1 hour)



Fig. 9: Sonoclot machine.

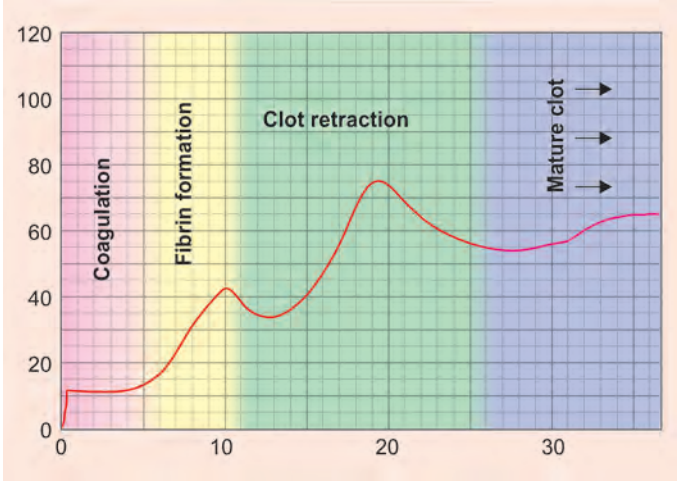

Fig. 10: Sonoclot signature phase.

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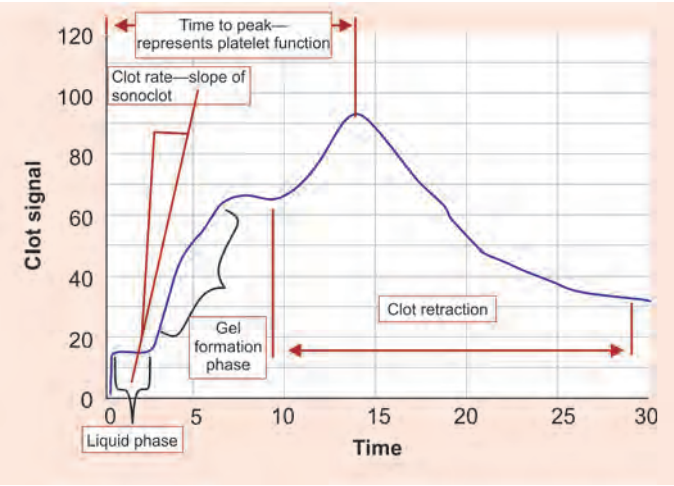
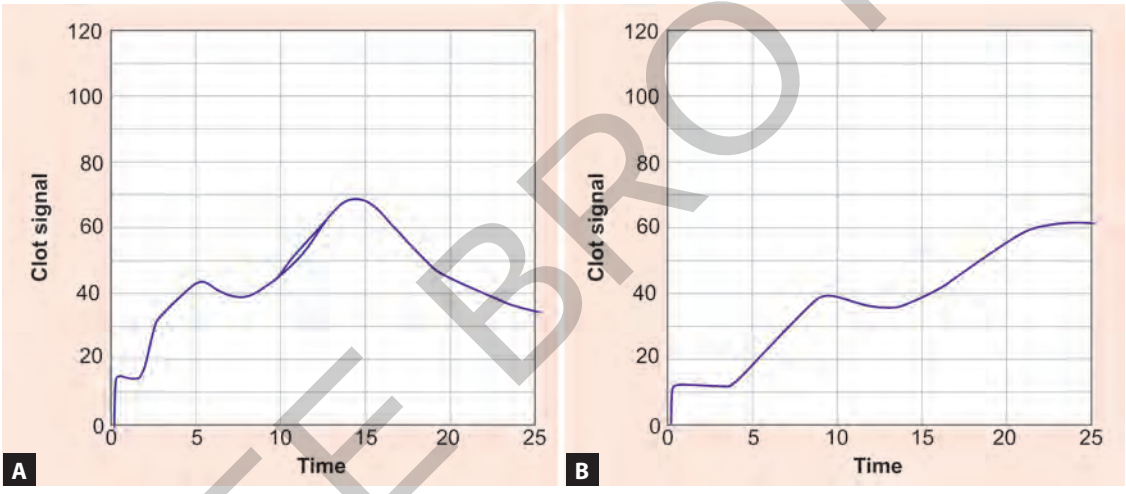


Fig. 11: Sonoclot signature interpretation.

TABLE 7: Sonoclot result interpretation.

Parameters	*Normal range*	*Interpretation*	*Elevated causes*	*Decreased causes*
Activated clotting time	100–155	Shows delay in initial clot formation	• Factor deficiency • Heparin effect	
Clot rate	9–35	Development of actual clot formation, indicator of heparin activity		Low fibrinogen
Platelet function	>1.6	Platelet function characterized by time to peak		• Platelet dysfunction • Thrombocytopenia



Figs. 12A and B: Sonoclot. (A) Normal; (B) Heparin effect—delayed initiation and slow clot rate.

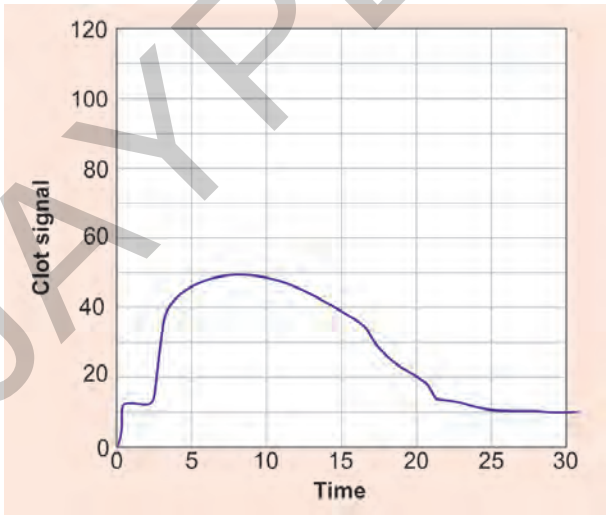


Fig. 13: Sonoclot—hyperfibrinolysis.

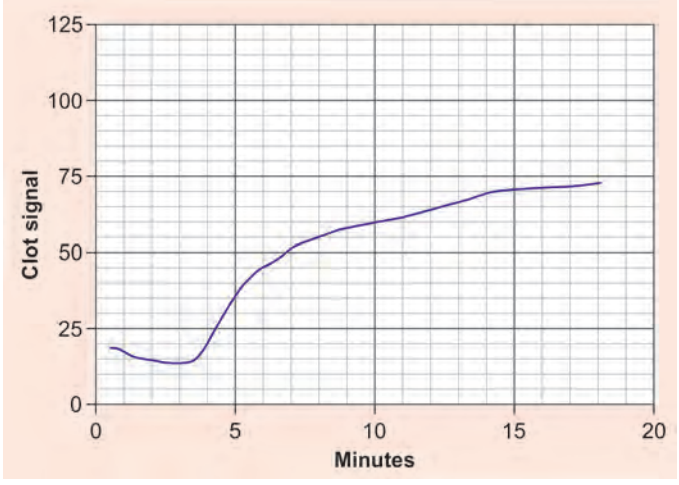


Fig. 14: Sonoclot—low factor and low platelet ACT—210 CR–18 PF–0.7. (ACT: activated clotting time; CR: clot rate; PF: platelet function)

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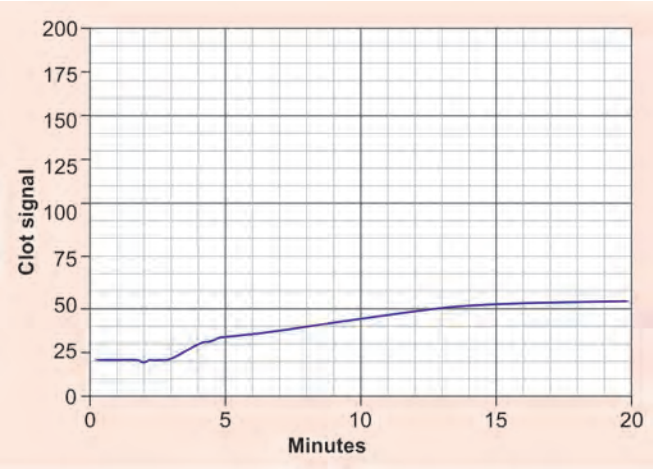

Fig. 15: Sonoclot—acute dilutional coagulopathy ACT—188 CR–6.1 PF–0.3. (ACT: activated clotting time; CR: clot rate; PF: platelet function)

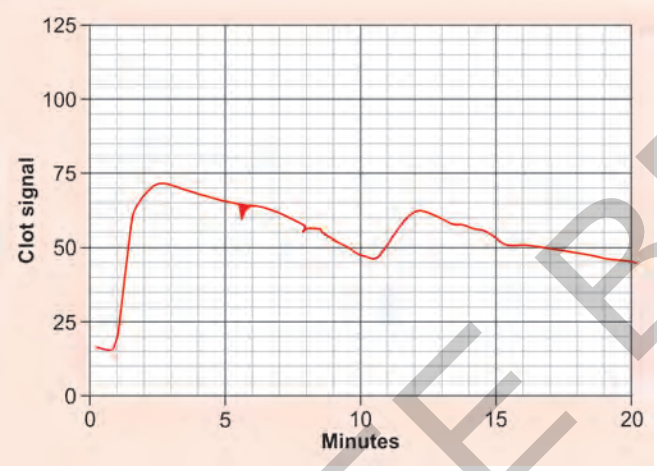

Fig. 16: Sonoclot hypercoagulable ACT—58 CR–75 PF–1.9. (ACT: activated clotting time; CR: clot rate; PF: platelet function)

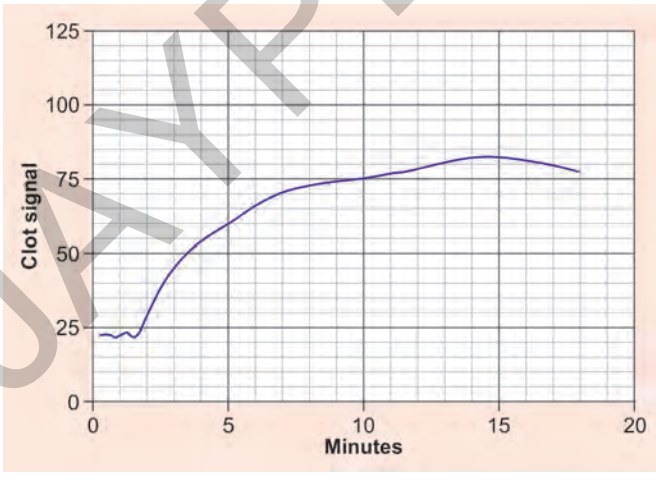

Fig. 17: Sonoclot—platelet dysfunction ACT—106 CR–28 PF–0.9. (ACT: activated clotting time; CR: clot rate; PF: platelet function)

MULTIPLE CHOICE QUESTIONS

1. **Heparin acts by accelerating the action of:**
   a. Prothrombin
   b. Thrombin
   c. Antithrombin
   d. Fibrin

2. **The normal ACT value in a nonheparinized patient is:**
   a. 50–100 seconds
   b. 200–220 seconds
   c. 90–150 second
   d. 169–240 seconds

3. **The ACT might be prolonged in all of the following circumstances, *except*:**
   a. Diuresis
   b. Oliguria
   c. Thrombocytopenia
   d. DIC

4. **Low levels of AT III in a patient on ECMO bypass may lead to:**
   a. Bleeding
   b. Thrombocytopenia
   c. Hemolysis
   d. Heparin resistance

5. **The ACT or "activated clotting time" is:**
   a. A bedside test of "true" clotting time
   b. Equivalent to the PT
   c. A bedside test of clotting function using an accelerant to obtain a quick result
   d. An unreliable test of clotting function

6. **A heparin bolus is given to the patient prior to ECMO cannulation in order to:**
   a. Prevent clotting of the ECMO cannula during the procedure
   b. Calibrate the bedside ACT machine
   c. Act as an antifibrinolytic on preexisting clots

7. **A heparin bolus might be given to a patient on bypass in all of the following circumstances, *except*:**
   a. An ACT value of 140
   b. Prior to a platelet transfusion
   c. Prior to cannulation
   d. Prior to decannulation

8. **Which of the following affects activated clotting time?**
   a. Heparin
   b. Diuresis
   c. FFP administration
   d. Platelets
   e. All of the above
   f. a and d

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9. Heparin functions by inhibiting the reactions that lead to the clotting of blood and the formation of fibrin clots. This action is carried out through:
a. The activation of anti-thrombin III
b. The inactivation of activated factor X
c. Inhibiting the conversion of prothrombin to thrombin
d. All of the above

10. The intrinsic pathway of the coagulation cascade can be measured with the following tests:
a. Anti-thrombin III levels, PT
b. Anti-thrombin III levels, bleeding time
c. Platelet count, bleeding time
d. aPTT, ACT

11. What is the antidote for argatroban?
a. Protamine
b. Vitamin K
c. No antidotes available
d. a and b

12. Argatroban is an anticoagulant and acts by:
a. Platelets inhibition
b. Binding with antithrombin III
c. Direct thrombin inhibition
d. All of above

13. All of the below are direct thrombin inhibitors, *except*:
a. Bivalirudin
b. Argatroban
c. Hirudin
d. Heparin
e. None of the above

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Pioneer in initiating ECMO program in critical care unit in India. Established Outreach (mobile) ECMO unit in 2010 and initiated and managed ECMO in 50 Tertiary Care Unit across India and provided mobile-ECMO services. Initiated ECMO transport in India and involved in many national and international transports. Have various publications on ECMO and are first to publish book on ECMO in India.

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