

# Quality Control in Clinical Laboratories

## Coagulation Tests, Peripheral Blood Smear and Staining



TEHRAN UNIVERSITY  
OF  
MEDICAL SCIENCES

Presented by Dr Shaban Alizadeh Professor of Laboratory Sciences and Milad Alahmoradi PhD student in Hematology and Blood Transfusion



# Fundamentals of Laboratory Quality Control

Quality Control (QC) is the cornerstone of Total Quality Management (TQM) in clinical laboratories. Effective QC systems ensure:

## Accuracy

Results closely reflect the true value (e.g., if actual PT is 12 seconds, test results show approximately 12 seconds)

## Precision

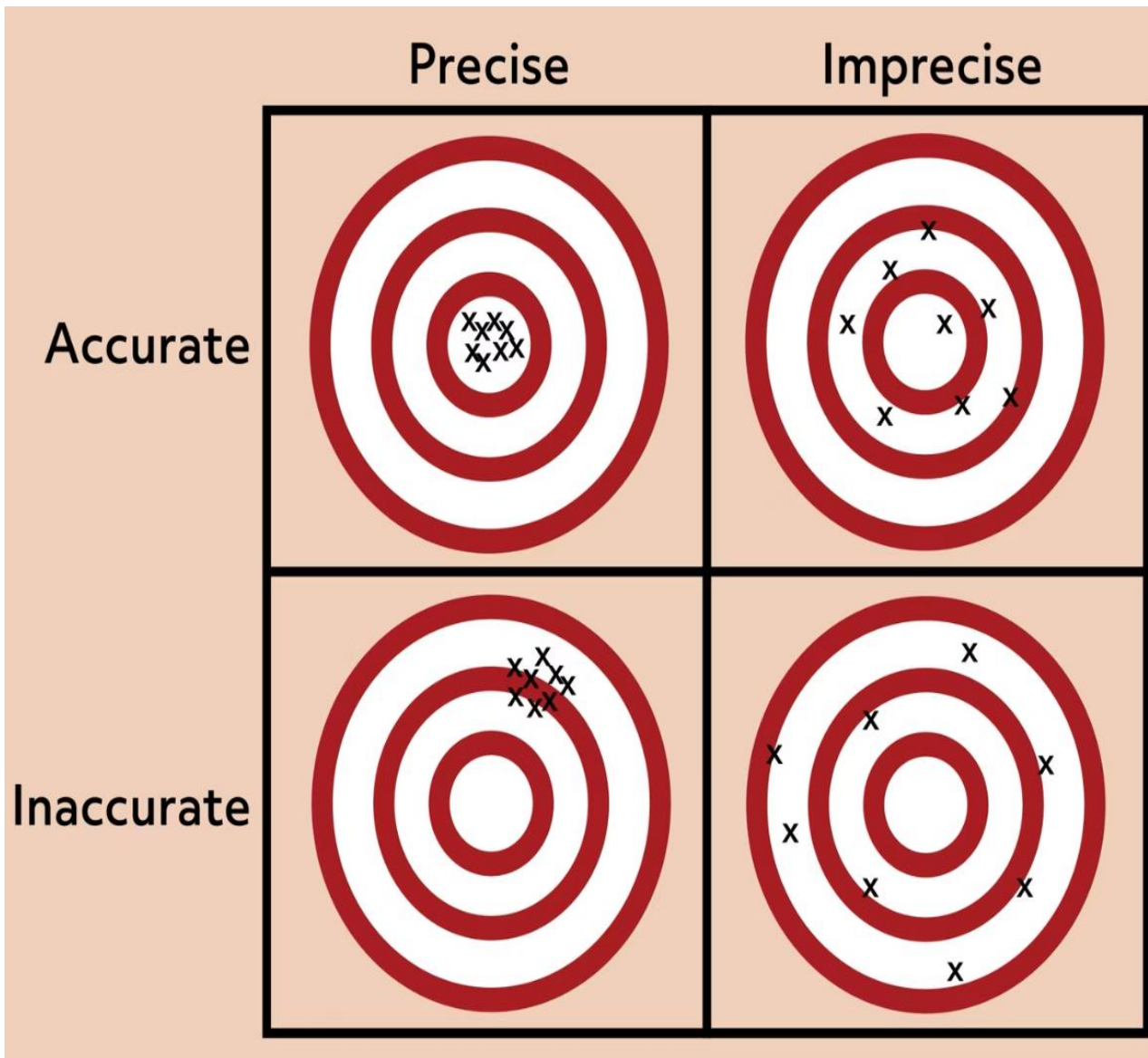
Low variability when the same test is repeated multiple times (e.g., 10 runs on one sample yield very similar results)

## Reproducibility

Consistent results across different testing conditions - operators, times, devices, and reagent lots

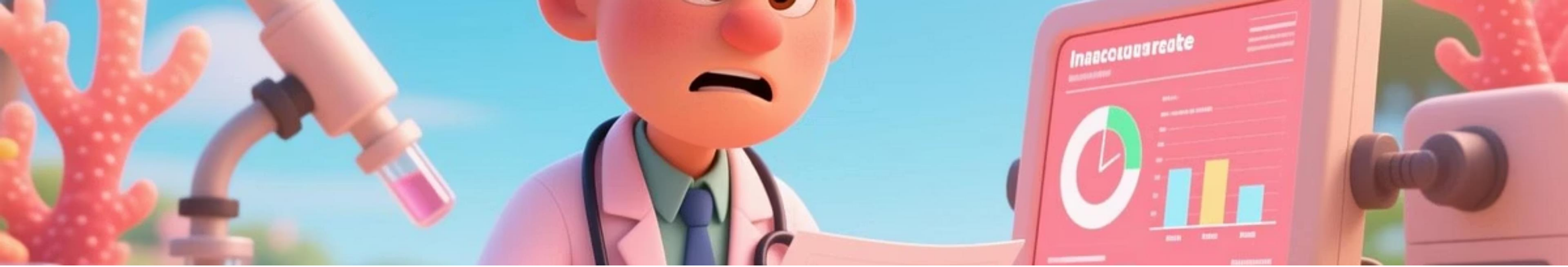


# The Critical Importance of Laboratory Quality Control



Quality control systems monitor laboratory testing processes to detect, reduce, and correct deficiencies before results are reported. They help maintain the integrity and reliability of testing procedures that directly impact patient care.

Without robust QC programs, laboratories risk producing inaccurate results that can lead to misdiagnosis, inappropriate treatment, delayed interventions, and potential harm to patients.



# Consequences of Inadequate Quality Control

## Systematic Errors

Ongoing instrument bias or calibration drift can produce consistently incorrect results, leading to systemic misdiagnosis. For example, consistently elevated INR values may result in inappropriate warfarin dose reductions.

## Random Errors

One-time events such as sample contamination or improper handling can cause erroneous results. For instance, an inaccurately prolonged aPTT might prompt a clinician to unnecessarily adjust heparin dosing, potentially causing dangerous bleeding or clotting events.

## Diagnostic Failures

Unreliable laboratory results can mask true pathologies or suggest conditions that aren't present, leading to missed diagnoses or unnecessary treatments that expose patients to avoidable risks.

# Quality Control Methodologies in Modern Laboratories



Testing laboratory

## Traditional QC

Utilizes commercial control materials with known values to verify system performance. These pre-made materials serve as reference standards to detect analytical errors. Controls are typically run at the beginning of each shift and after system maintenance.



## Patient-Based QC (PBQC)

Leverages actual patient data to monitor testing quality, providing more realistic assessment of system performance. PBQC methods include moving averages, delta checks, and patient means to detect subtle shifts in analytical performance.



## Patient-Based Real-Time QC (PBRTQC)

Employs advanced software algorithms to analyze patient results in real-time, enabling immediate detection of analytical problems. These systems can alert laboratory staff to potential issues before reporting results.

---

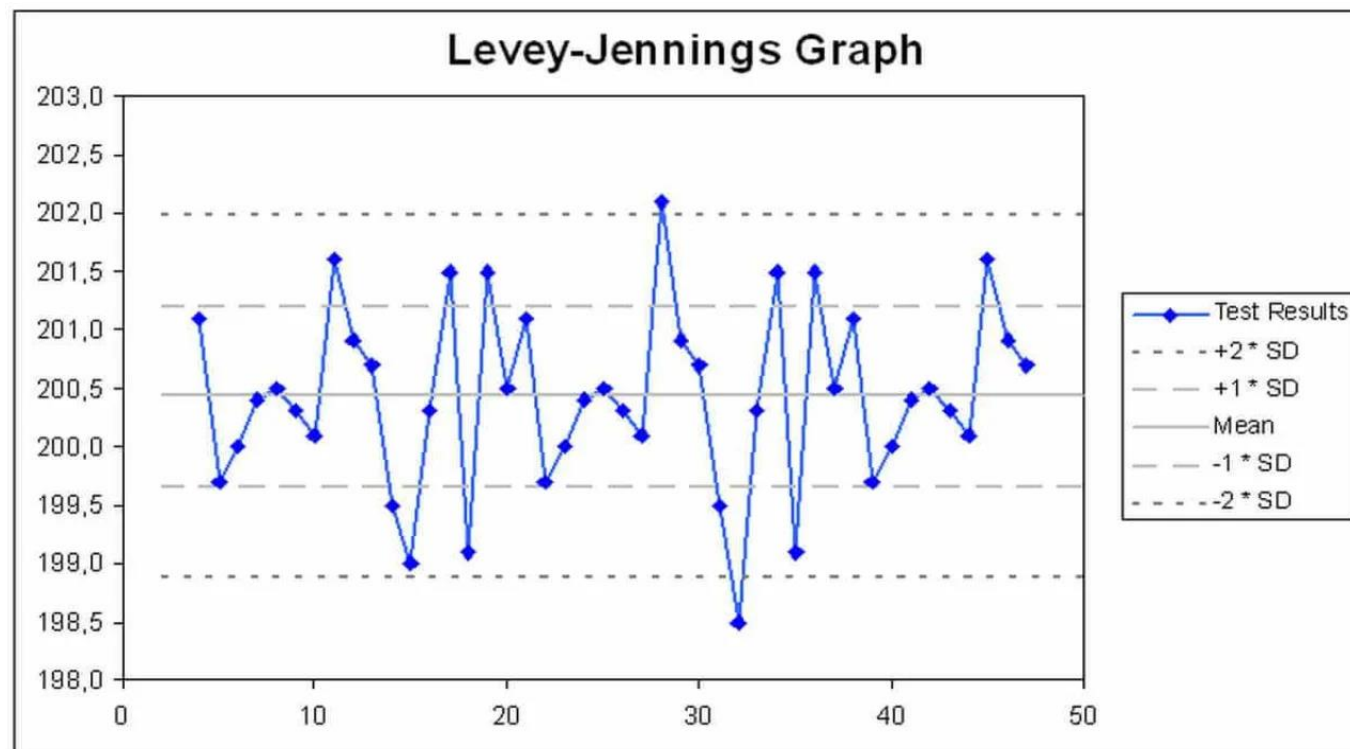
	<b>Traditional QC</b>	<b>PBQC (Patient-Based Quality Control, Periodic)</b>	<b>PBRTQC (Patient-Based Real-Time Quality Control)</b>
<b>Data Source</b>	Commercial controls	Patient results (periodic)	Patient results (real-time)
<b>Frequency</b>	Several times a day	When sufficient data is available	Continuously, with each new result
<b>Time Coverage</b>	Limited coverage between two QC	Broader, coverage many patients	Complete and continuous
<b>Sensitivity</b>	Medium	Good (with moving average, delta check)	Excellent (with EWMA, CUSUM)
<b>Error Detection</b>	Delayed, later	Retrospective	Real-time
<b>Reaction to Outliers</b>	Unnecessary, controls are stable	Removal or statistical adjustment	Immediate prevention of reporting incorrect results
<b>Main Application</b>	Guarantee Standard of instrument	Evaluates actual performance in patients	Immediate prevention
<b>Main Advantage</b>	Standard and accepted in accreditation	Clinical reality	Sensitive, preventive

---

# Traditional Internal QC for Coagulation Tests

## Daily Control Procedures

- Run at least two commercial control levels (normal and abnormal) at the start of each shift
- Plot results on a Levey-Jennings chart to visualize trends and shifts over time
- Document and review all control data daily
- Verify reagent lot numbers and expiration dates



## Westgard Rules

Statistical rules to detect random and systematic errors:

- **13s:** One result  $>3$  SD from mean (random error)
- **22s:** Two consecutive  $>2$  SD (systematic error)
- **R4s:** Two results differing by  $>4$  SD (random error)
- **41s:** Four consecutive  $>1$  SD on one side (trend/shift)
- **10x:** Ten consecutive on one side of mean (bias)

When rules are violated, stop testing, investigate root causes, implement corrective actions, and verify resolution before resuming patient testing.

# Total Allowable Error Limits for Coagulation Tests

Based on CLIA 2025 proficiency testing acceptance limits (implemented January 1, 2025):

**±15%**

**PT**

Target Value ±15%

**±15%**

**INR**

Target Value ±15%

**±15%**

**aPTT**

Target Value ±15%

CLIA 2025 standardize

**±20%**

**Fibrinogen**

Target Value ±20%

Total Allowable Error (TEa) represents the maximum acceptable deviation from the target value. Results exceeding these limits are considered invalid and require investigation, corrective action, and repeat testing.

# Patient-Based QC (PBQC) for Coagulation Tests

## Patient Mean

Calculate average PT/aPTT from 20-50 consecutive patients

≥10% deviation from historical mean triggers investigation

Useful for detecting reagent deterioration or instrument drift

## Delta Check

Compare current result to patient's previous value

>20% change without clinical explanation warrants investigation

Effective for identifying pre-analytical or individual sample errors

## Moving Average

Calculate rolling mean of sequential results  
>2 SD shift indicates potential precision issues

Algorithms like Bull's algorithm facilitate automation

## Advantages

- Cost-effective (saves ~30% on control materials)
- Uses realistic samples that reflect actual testing conditions
- Can detect subtle shifts missed by traditional QC

## Challenges

- Requires high testing volume (>100 samples/day) for statistical validity
- Patient variability affects interpretation (e.g., pregnancy affects PT)

# Troubleshooting Coagulation QC Issues



## **Check Reagent Integrity**

Verify expiration date, proper storage conditions. Inspect for unusual appearance or cloudiness.

## **Recalibrate Analyzer**

Follow manufacturer's instructions for calibration procedure. Ensure proper maintenance has been performed.

## **Replace Control Material**

Use fresh control material if current lot is suspect. Verify proper handling and storage of controls.

## **Hold Patient Results**

Withhold all patient results until the issue is resolved to prevent reporting potentially erroneous values.

# Section 1: Quality Control of Coagulation Tests

## PT (Prothrombin Time)



Evaluates the extrinsic coagulation pathway and factors I, II, V, VII, X

## aPTT



Evaluates the intrinsic pathway and factors I, II, V, VIII, IX, X, XI, XII

## INR



Standardized PT ratio used for monitoring warfarin therapy



# Coagulation Tests in Clinical Laboratories

In clinical diagnostic laboratories, coagulation assays such as PT (Prothrombin Time), aPTT (Activated Partial Thromboplastin Time), INR (International Normalized Ratio), and Bleeding Time are performed to evaluate the hemostatic system.

These tests are essential for diagnosing bleeding disorders, assessing coagulation factor activity, and monitoring anticoagulant therapy (e.g., warfarin, heparin).

The following guide, based on CLSI and ISTH standards, describes the principles of operation, calculation, setup, and quality control (QC) for each test.



# General Pre-Analytical Procedures for All Coagulation Tests

01

---

## Specimen Collection

- Venous blood should be collected in 3.2% sodium citrate tubes (blood-to-anticoagulant ratio of 9:1).
- Avoid using EDTA or heparinized tubes.
- Samples must be free from clots, hemolysis, or lipemia.

03

---

## Plasma Preparation

- Centrifuge at 1500–2000 g for 10–15 minutes to obtain platelet-poor plasma (PPP) with platelet count  $\leq 10 \times 10^9/L$ .
- For lupus anticoagulant or other sensitive assays, a double centrifugation step is recommended.

02

---

## Transportation

Transport samples at room temperature (18–24°C) and deliver to the laboratory within 1 hour of collection.

04

---

## Sample Stability

- PT/INR: Stable up to 24 hours at room temperature.
- aPTT (without heparin): Stable up to 4 hours.
- Heparinized samples: Should be processed within 1 hour.
- For longer storage: freeze at  $-20^\circ\text{C}$  (up to 2 weeks) and thaw at  $37^\circ\text{C}$ . Avoid repeated freeze–thaw cycles.

# Prothrombin Time (PT)

## Purpose

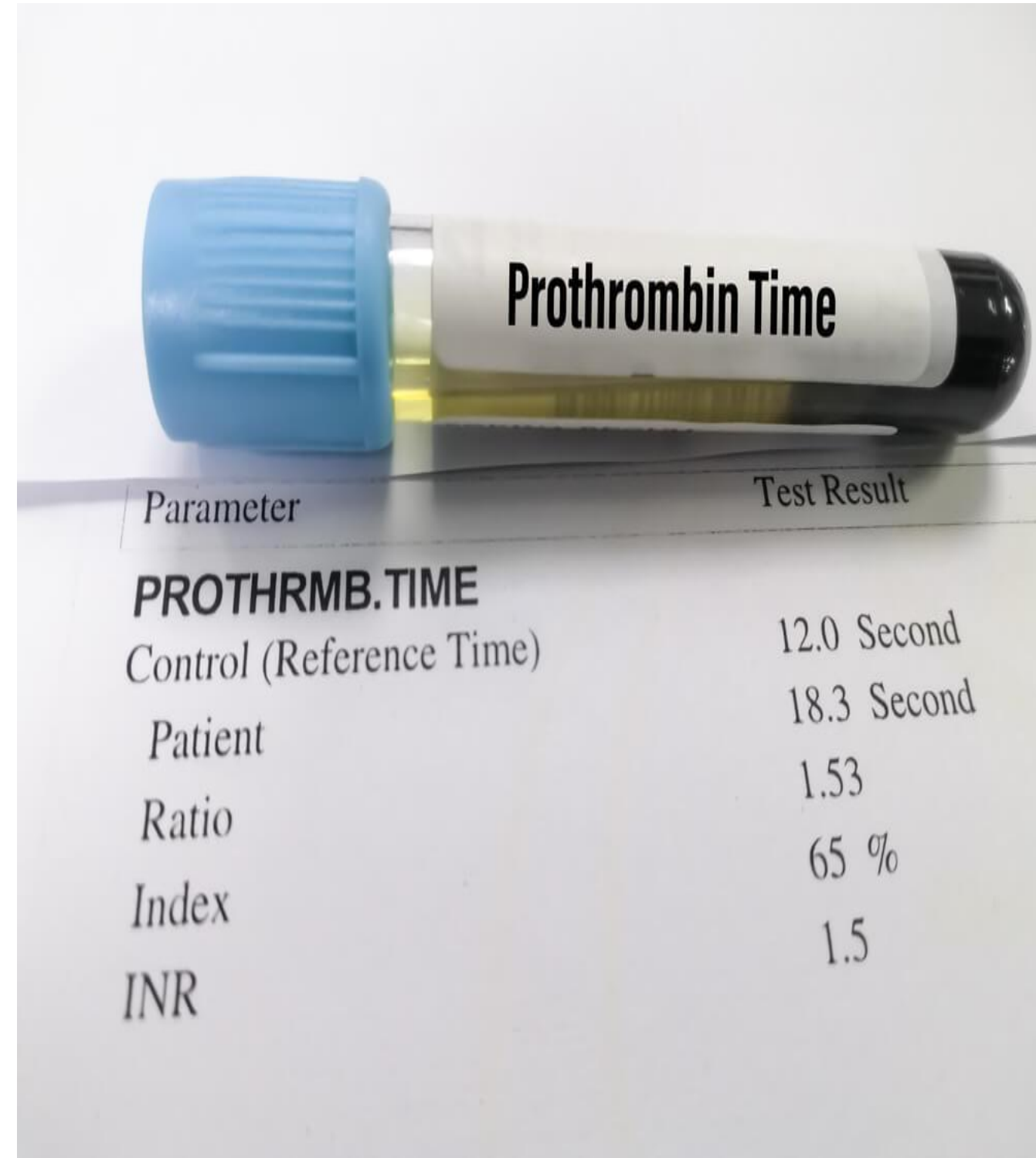
Evaluates the extrinsic coagulation pathway (factors VII, X, V, II, and fibrinogen).

## Procedure

1. Warm plasma to 37°C.
2. Mix 100  $\mu$ L of plasma with 200  $\mu$ L of thromboplastin reagent (tissue factor + calcium).
3. Measure the time to clot formation (manually or with a coagulometer, e.g., Sysmex CS-2500).
4. Normal range: approximately 11–15 seconds.

## Calculation

Reported in seconds. In patients on anticoagulant therapy, results are converted to INR.



# PT Setup and Quality Control

## Setup

- Choose a thromboplastin reagent with an ISI close to 1.0 (human, bovine, rabbit, or recombinant origin).
- Calibrate ISI locally using reference plasma (20 healthy donors + 60 stabilized patients).
- Run both normal and abnormal controls each shift.

## Quality Control (QC)

- **Mean Normal PT (MNPT):** Derived from at least 20 healthy donors (equal male/female distribution, no anticoagulants).
- Example: Mean = 11.3 sec, SD = 0.72 sec → Reference range = 9.8–12.7 sec.
- **Reference Range** = Mean  $\pm$  2  $\times$  SD
- **Levey–Jennings Chart:** Plot control results (normal and abnormal) against mean  $\pm$ 1SD,  $\pm$ 2SD,  $\pm$ 3SD; apply Westgard rules for error detection.
- **Acceptable CV:** 5–10%.

# Activated Partial Thromboplastin Time (aPTT)

## Purpose

Assesses the intrinsic and common coagulation pathways (factors XII, XI, IX, VIII, X, V, II, and fibrinogen) and monitors heparin therapy.

1

Procedure Step 1

Mix 100  $\mu\text{L}$  of plasma with 100  $\mu\text{L}$  of aPTT reagent (phospholipid + activator such as silica or kaolin).

2

Procedure Step 2

After incubation, add 100  $\mu\text{L}$  of  $\text{CaCl}_2$  and record clotting time.

3

Normal Range

Approximately 25–35 seconds.

# Calculation

Report time in seconds.

For heparin monitoring: **aPTT ratio** = **aPTT<sub>patient</sub> / MNPTT**

Therapeutic range: 1.5–2.5× MNPTT

# Setup

- Choose a reagent sensitive to factor deficiencies or lupus anticoagulant (e.g., Actin FS or Actin FSL).
- Establish a therapeutic calibration curve for heparin (0.3–0.7 IU/mL).

# Quality Control (QC)

- Derive mean and SD from at least 20 healthy donors.
- Example: Mean = 29.6 sec, SD = 1.9 sec → Reference range = 25.8–33.4 sec.
- Use Levey–Jennings charts and Westgard rules to monitor performance.
- Acceptable CV: 5–15%.
- Heparinized samples should be processed immediately.
- Participate in EQA programs to assess reagent sensitivity to lupus anticoagulant.

# International Normalized Ratio (INR)

## Purpose

Standardizes PT results for monitoring vitamin K antagonist therapy (e.g., warfarin).

### Calculation Formula

$$INR = \left( \frac{PT_{patient}}{MNPT} \right)^{ISI}$$

- **ISI:** International Sensitivity Index (provided by manufacturer or determined locally).

### Normal Range

0.8–1.2

### Therapeutic Range

2.0–3.0

(varies by clinical condition)

# Bleeding Time

## Purpose

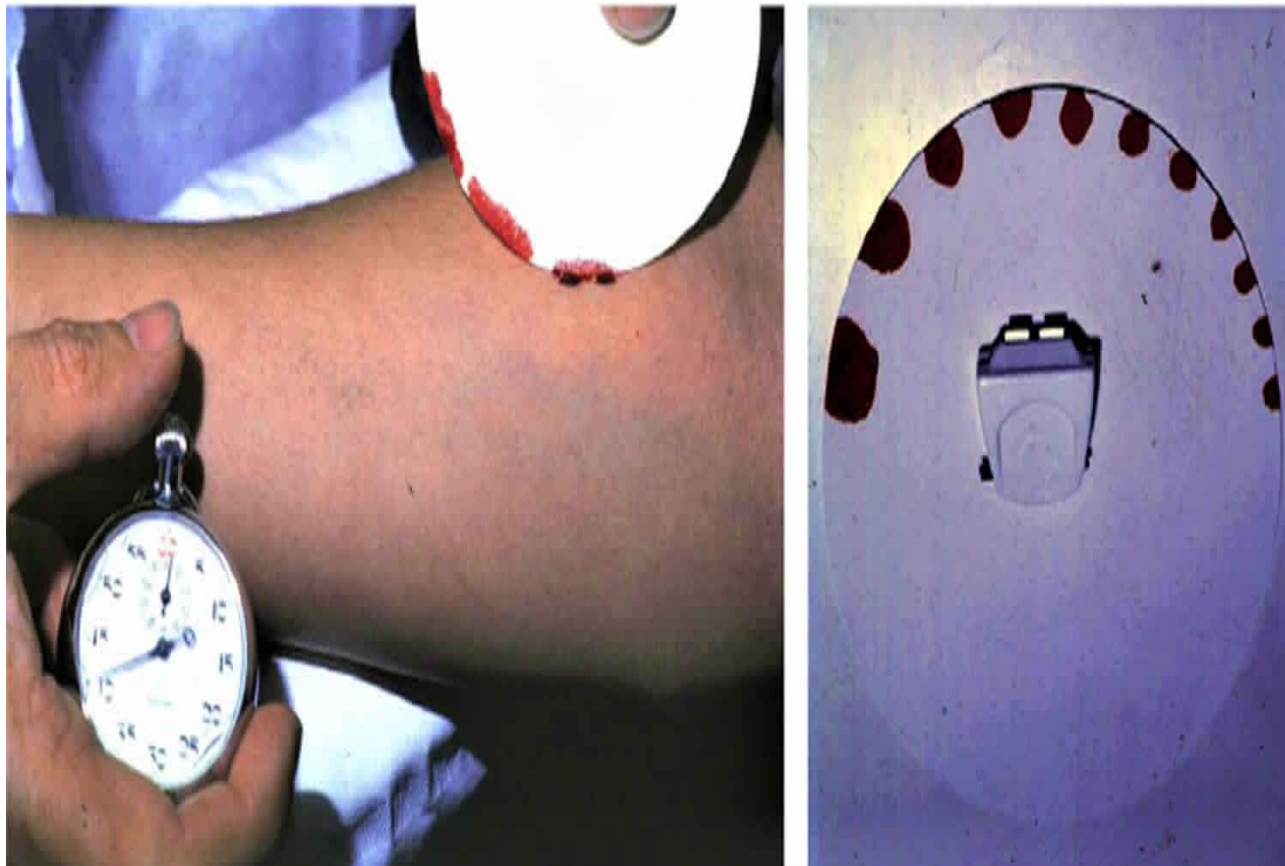
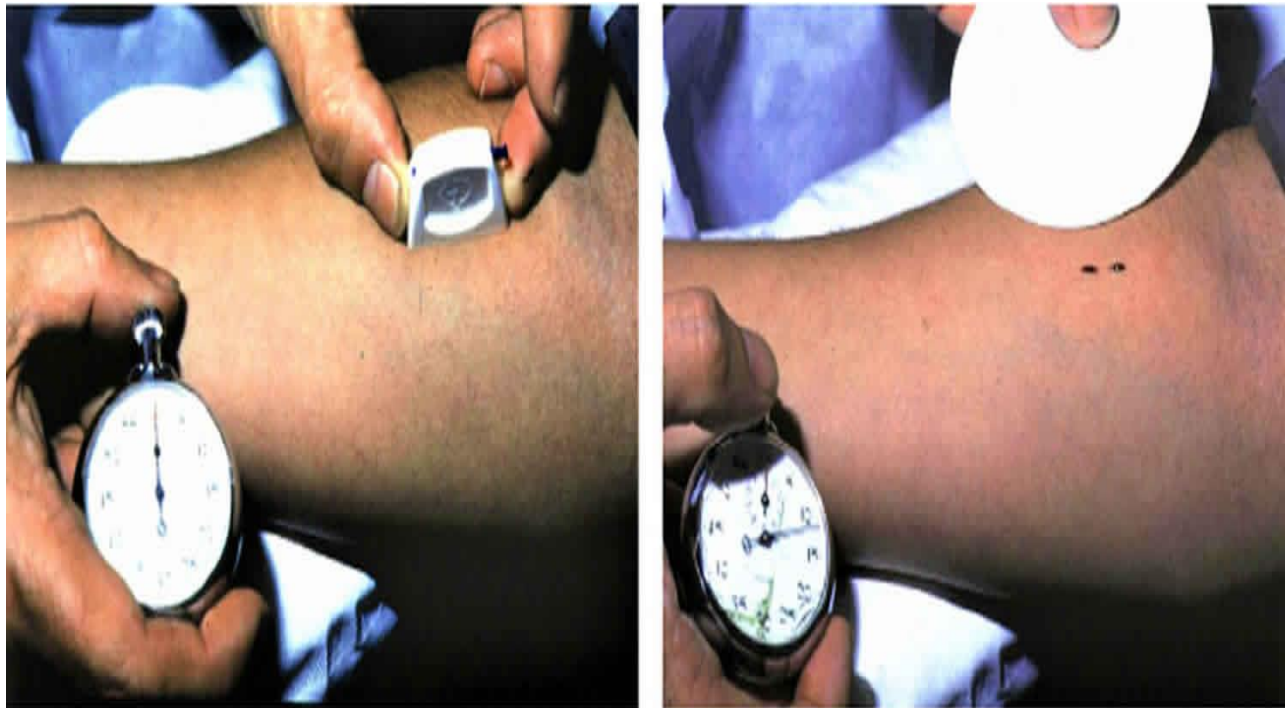
Assesses platelet function and vascular integrity (now largely replaced by the PFA-100/200 platelet function analyzer).

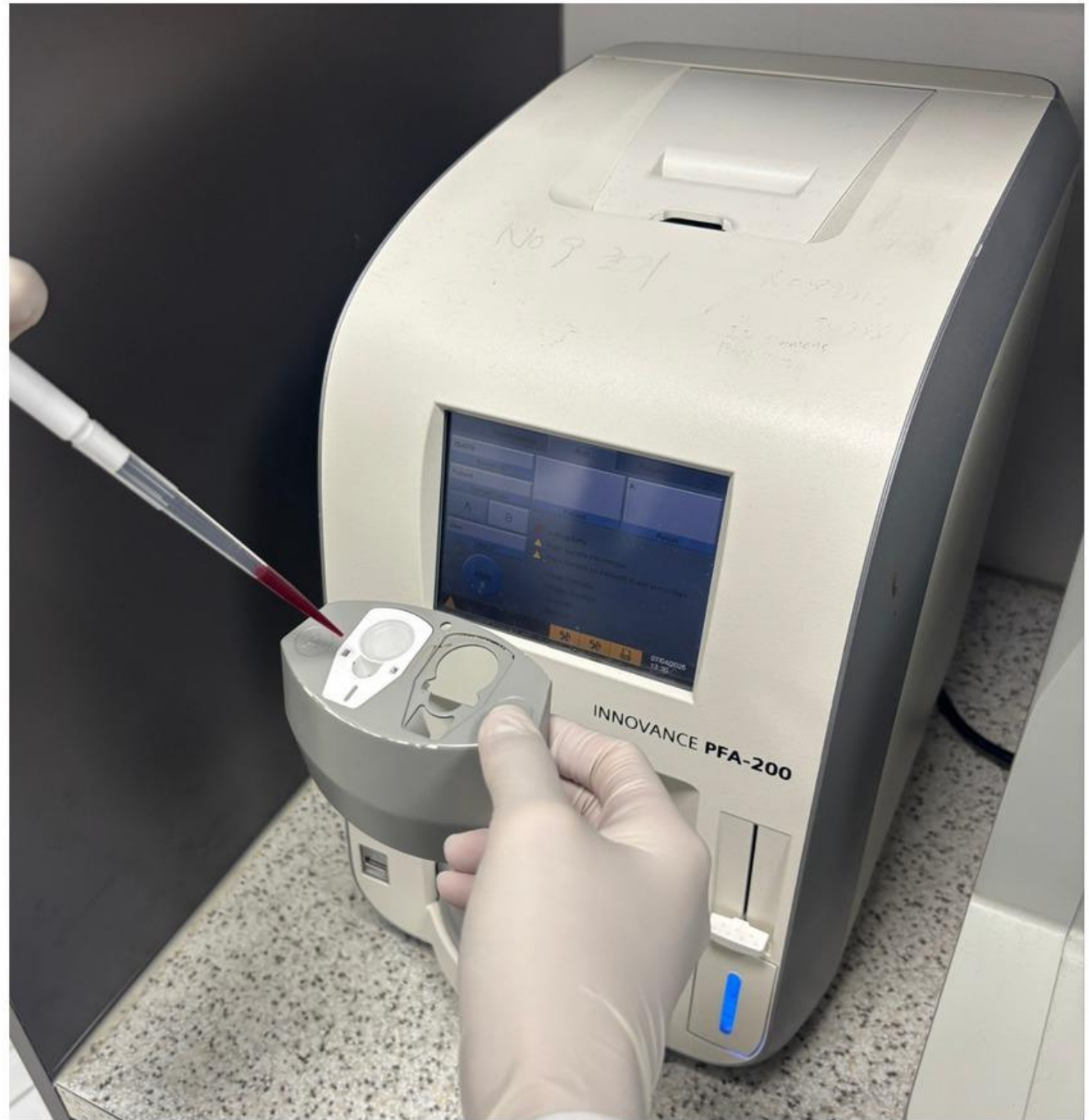
## Procedure

1. Inflate a blood pressure cuff to 40 mmHg on the upper arm.
2. Make a standardized incision on the forearm (1 mm deep, 10 mm long) using a standardized lancet (e.g., Surgicutt).
3. Blot blood gently with filter paper every 30 seconds until bleeding stops.
4. Normal range: 2–9 minutes.

## Quality Control

- Establish local reference range from  $\geq 20$  healthy individuals.
- No Levey–Jennings monitoring (manual test), but lancet performance, cuff pressure, and operator skill must be checked daily.
- If available, replace with PFA-100 for better reproducibility.





# Instrument QC and Maintenance Parameters

Parameters	Quality Control Activities	Frequency
Coagulometer	Run daily QC (normal & abnormal controls), calibrate every 6 months or after service, check temperature, timer, optical path	Daily / Semiannual
Centrifuge	Verify RPM with tachometer (5 readings), check timer/balance, preventive maintenance	Semiannual
Pipettes	Calibrate gravimetrically, check precision and accuracy ( $\pm 1.5\%$ )	Semiannual
Water Bath (37°C)	Verify temperature uniformity with certified thermometer	Daily
Thermometers & Balances	Calibrated by certified agency	Annual

# Pre-Analytical Quality Control for Coagulation Tests

Pre-analytical variables significantly impact coagulation test results. Proper sample handling is essential for accurate testing.

## Tube and Anticoagulant

- Use 3.2% sodium citrate tubes (light blue top)
- Maintain strict 9:1 blood-to-citrate ratio
- Underfilling causes falsely prolonged PT/aPTT

## Centrifugation

- Process at 1500g for 15 minutes
- Maintain room temperature (not cold)
- Double-spin for platelet-poor plasma when needed

## High Hematocrit Adjustments

- For hematocrit >55%, adjust citrate volume
- Formula:  $\text{New citrate volume} = (1.85 \times 10^{-3}) \times (100 - \text{HCT}) \times \text{blood volume}$

## Sample Stability & Rejection

- PT stable  $\leq 24$  hours at room temperature
- aPTT within 4 hours or freeze at  $-70^{\circ}\text{C}$
- Reject clotted or severely hemolyzed samples

⊗ **Critical Example:** An underfilled tube (6mL tube with only 4mL blood) might show PT of 15 seconds instead of the actual 12 seconds, potentially leading to misdiagnosis of a coagulation disorder. Always visually check fill level.

# Common Analytical Issues

## Hemolysis in Coagulation Testing

### Hemolysis Effects on Coagulation Parameters

Hemolysis (red blood cell rupture) releases hemoglobin and intracellular components that interfere with coagulation testing through multiple mechanisms:

- Released hemoglobin interferes with optical detection systems in automated analyzers
- Phospholipids from ruptured cell membranes can activate coagulation pathways
- Intracellular enzymes may degrade coagulation factors

#### Impact on test results:

- Fibrinogen: Falsely elevated by 15-20% in turbidimetric assays
- aPTT: prolonged (5-7 seconds increase)
- PT: prolonged (1-2 seconds increase)

**Solution:** Use gentle venipuncture technique with proper 21-23 gauge needles. Visually inspect samples for pink/red discoloration.



⊗ **Example:** A hemolyzed sample might increase fibrinogen from 250 to 300 mg/dL, aPTT from 30 to 35 seconds, and PT from 12 to 13 seconds, suggesting a false coagulopathy. Always collect a fresh, non-hemolyzed sample if hemolysis is detected.

# Heparin Contamination



## Heparin Effects on Coagulation Parameters

Heparin, a potent anticoagulant, significantly impacts coagulation test results through:

- Direct inhibition of thrombin activity
- Enhanced antithrombin III activity
- Interference with multiple steps in the coagulation cascade

### Common sources of contamination:

- Drawing blood through heparin-flushed catheters or lines
- Cross-contamination from heparinized tubes
- Recent therapeutic heparin administration

⊗ **Example:** Heparin contamination might extend PT from 12 to 18 seconds, aPTT from 30 to >50 seconds, and reduce fibrinogen from 200 to 150 mg/dL. Always verify the sample source and collect from a peripheral vein when possible.

**Solution:** Confirm no recent heparin therapy, avoid drawing through heparin-flushed lines, use dedicated citrate tubes.



# Reagent Degradation

## Impact on Coagulation Parameters

Degraded or contaminated reagents lead to erroneous results across all coagulation tests:

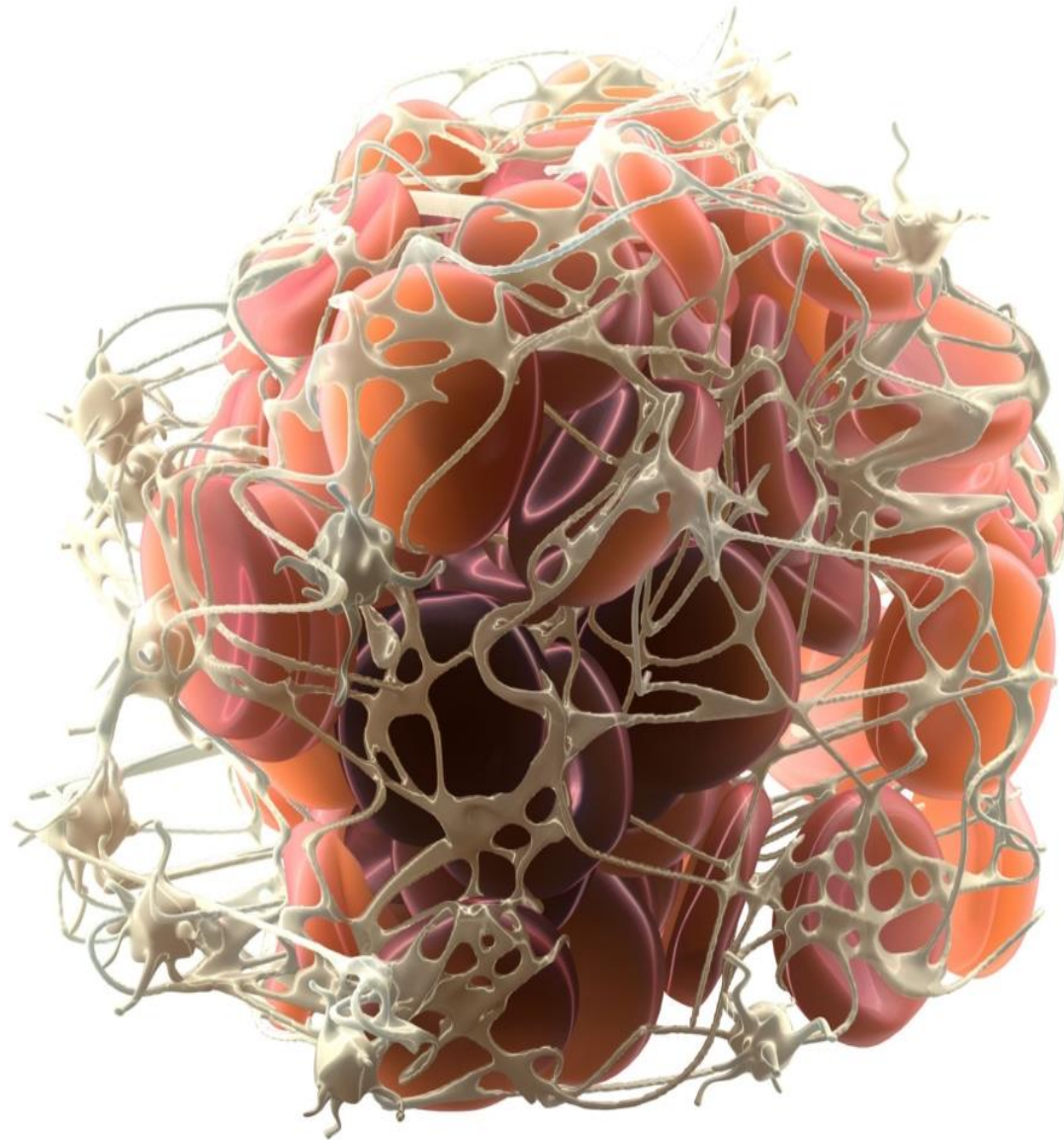
- Thromboplastin (PT): Loss of potency causes prolonged results
- Partial thromboplastin (aPTT): Deterioration leads to variable or prolonged results
- Thrombin (fibrinogen): Decreased activity produces falsely low fibrinogen values

## Detection and Prevention

- Maintain strict inventory management with FIFO (first in, first out) principle
- Store reagents at manufacturer-specified temperatures (typically 2-8°C)
- Inspect reagents visually for turbidity, particles, or discoloration before use
- Filter turbid reagents using approved methods before testing

**⚠ Example:** An aged thrombin reagent might produce fibrinogen results of 180 mg/dL instead of the actual 200 mg/dL, PT of 15 seconds instead of 12, and aPTT of 35 seconds instead of 30. Always replace reagents showing performance deterioration and verify with controls.

# High Fibrinogen Levels



## Impact of Acute Phase Reactions

Elevated fibrinogen (>700 mg/dL) from acute phase responses can affect testing through:

- Exceeding assay linearity in fibrinogen measurements
- Increased plasma viscosity affecting flow dynamics
- Potential shortening of aPTT due to hypercoagulability
- Minimal direct impact on PT but possible interference

## Clinical Causes of Elevated Fibrinogen

- Acute inflammation
- Infection
- Pregnancy (especially third trimester)
- Malignancy
- Tissue injury

❏ **Solution:** Dilute samples with elevated fibrinogen according to assay protocols (typically 1:5 or 1:10 with buffer). Verify CRP or other acute phase proteins if inflammation is suspected.

# External Quality Assessment for Coagulation Tests

## EQA Program Requirements

- Participate in proficiency testing programs at least 3 times per year
- Compare your laboratory's results with peer laboratories using similar methodologies
- Calculate Standard Deviation Index (SDI) to quantify performance
- Acceptable performance:  $SDI < 2$  (within two standard deviations of peer mean)
- Document all EQA results and corrective actions
- Perform root cause analysis for any unacceptable results



**⚠ Example:** If EQA shows your PT results consistently biased high compared to peer laboratories, review internal QC logs for similar trends, check calibration, and verify reagent performance.

# Section 2: Quality Control of Peripheral Blood Smear

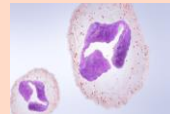


Peripheral Blood Smear (PBS) examination is a critical diagnostic tool for evaluating blood cell morphology and detecting hematologic disorders.



## RBC Evaluation

Examined for size (microcytic, normocytic, macrocytic), shape (poikilocytosis), color (hypochromic, normochromic), and inclusions (Howell-Jolly bodies, basophilic stippling)



## WBC Assessment

5-part differential count and morphological examination to identify abnormal cells (blasts, reactive lymphocytes) and assess maturation



## Platelet Evaluation

Estimation of number (to verify automated counts) and assessment of size and morphology (giant platelets, platelet clumps)

Unlike automated testing, PBS examination is highly manual and relies on individual expertise, making standardized QC practices essential.

# Traditional QC for Peripheral Blood Smear



## Preparation Standardization

- Use fresh EDTA blood (<2 hours old for optimal morphology)
- Control drop size (small 2-3mm drop for consistency)
- Spread at 30-45° angle with smooth, continuous motion
- Smear should cover 2/3 of slide with proper feathered edge
- Air-dry quickly to prevent artifact formation

## Morphology Control Practices

- Compare to reference smears (normal and pathological examples)
- Maintain a library of validated cases (e.g., sickle cell, megaloblastic anemia)
- Count minimum of 100 WBCs for accurate differential
- Review at least 10 fields in monolayer area before reporting

## Quality Verification

- Ensure uniform distribution with no ridges or artifacts
- Verify presence of adequate monolayer area for examination
- Participate in quarterly proficiency testing programs
- Implement systematic slide review by senior staff

# Patient-Based QC for Peripheral Blood Smear

## Morphology Mean

Calculate average indices (e.g., % anisocytosis, % poikilocytosis) from 50 consecutive smears

Unexpected rises in morphological findings can flag preparation or staining issues

Example: Sudden increase in reported spherocytes might indicate improper spreading technique

## Delta Check

Compare sequential patient smears for unexplained morphological changes

Sudden appearance of abnormal cells without clinical explanation warrants investigation

Example: New cells reported without treatment changes might indicate smear artifact or stain precipitate

## PBRTQC

Utilize digital scanners with AI algorithms to analyze morphological trends

Alert for >10% variation in standardized parameters (e.g., RBC size distribution)

Example: AI detection of consistent reporting bias between technologists

## Advantages

- Uses real patient data reflecting actual conditions
- Reduces costs compared to commercial controls
- Helps identify subtle examiner bias or drift

## Challenges

- Patient variability (e.g., infection alters morphology)
- Need to filter by patient groups for meaningful comparison
- Requires sophisticated software for effective implementation

# Practical Example: PBS Quality Issues



## **Problem: Cells Cluster at Slide Edges**

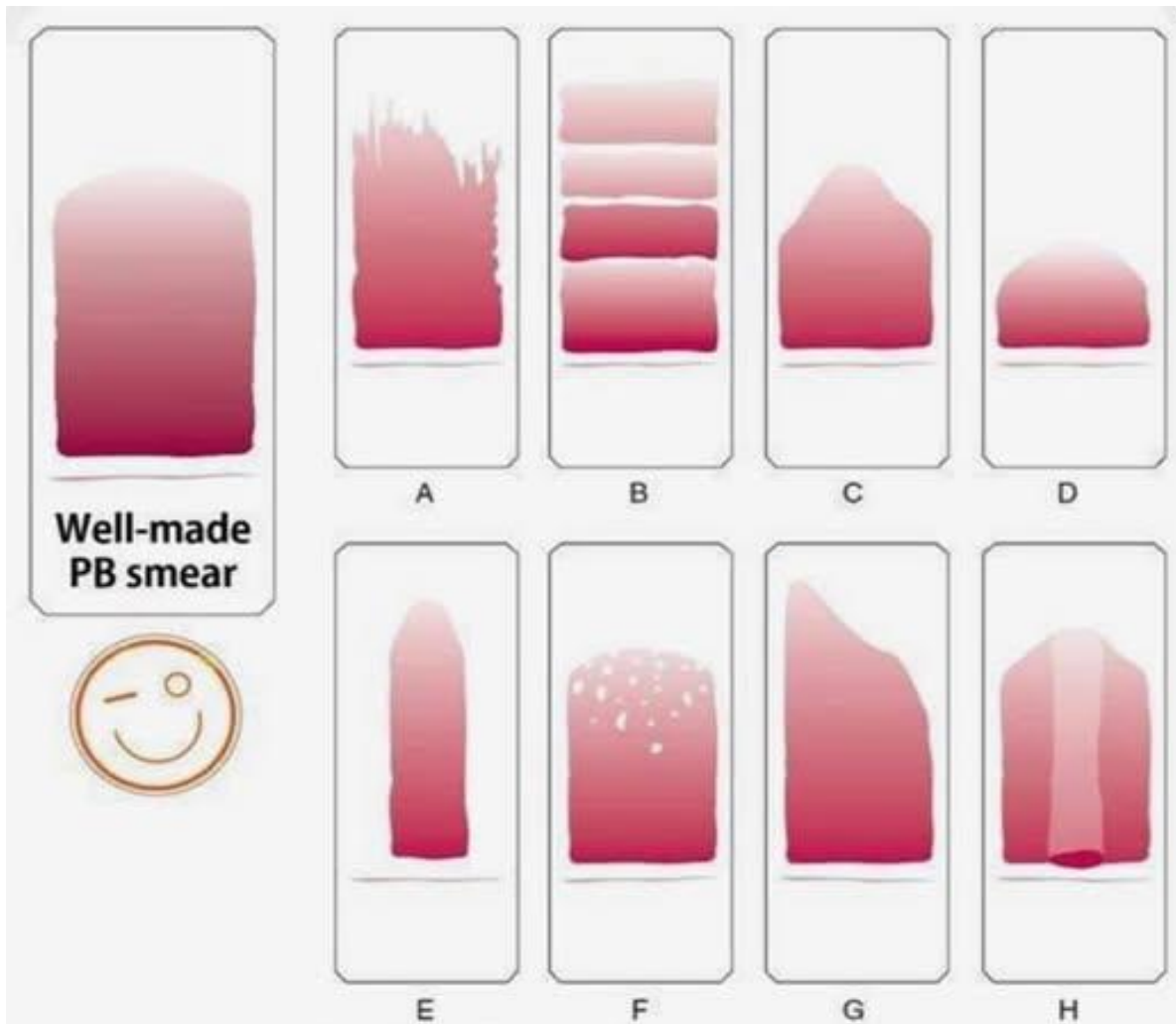
### **Likely Causes:**

- Slow spreading technique allowing cells to settle
- Greasy or contaminated slide surface
- Improper angle during spreading (too steep)
- Excessive delay between drop placement and spreading

### **Appropriate Responses:**

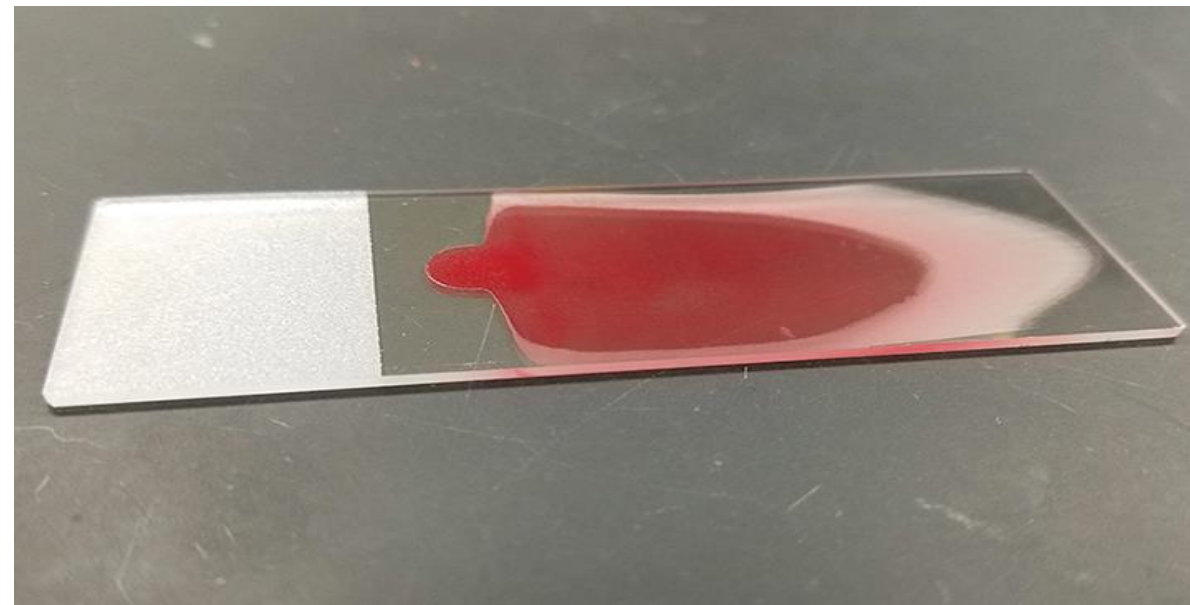
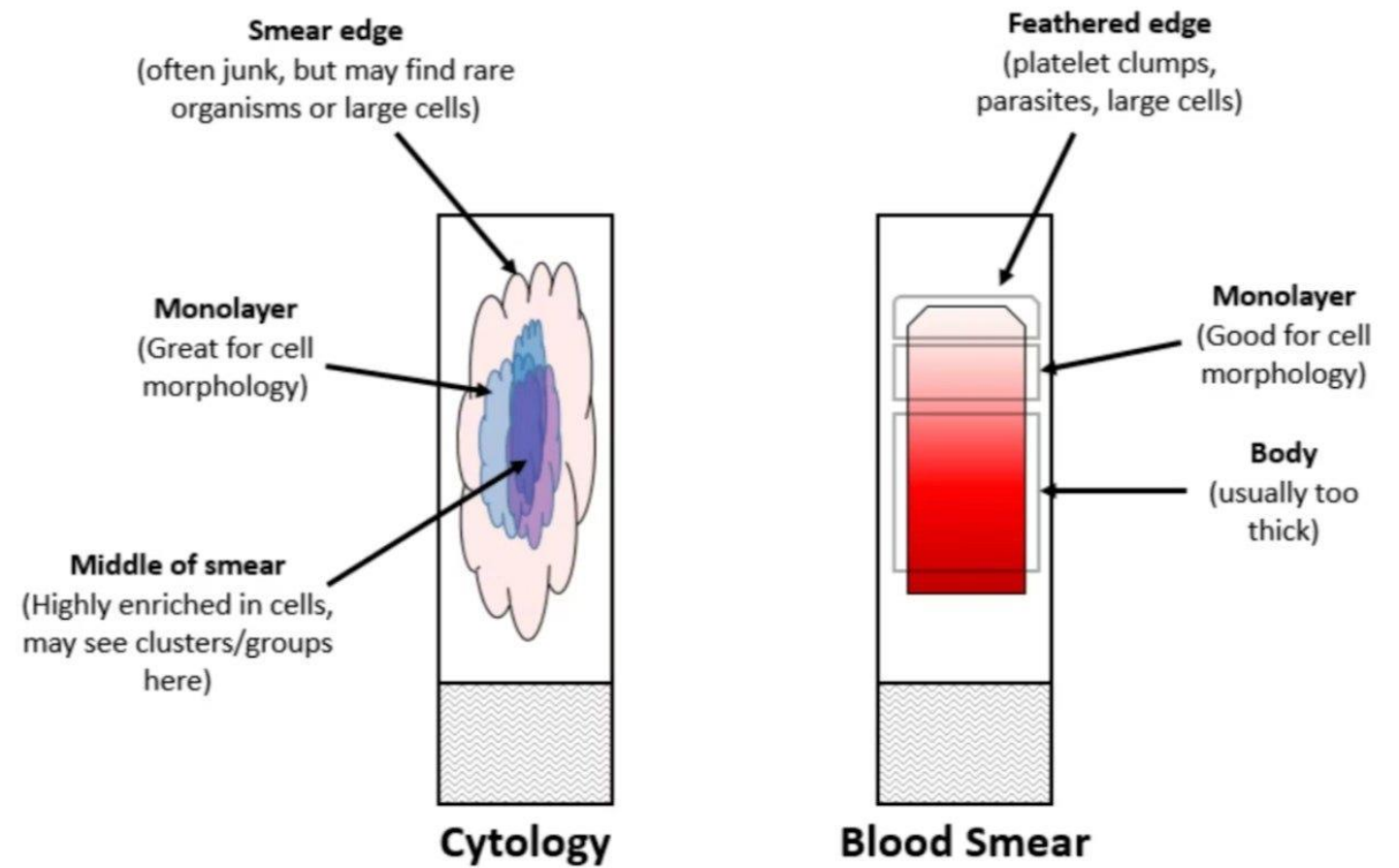
- Reject the slide - it cannot provide accurate morphological assessment
- Retrain technician on proper spreading technique
- Implement rapid spreading after drop placement (within 3 seconds)

In PBQC systems, a sudden increase in rejected slides might indicate technician technique that require immediate intervention.



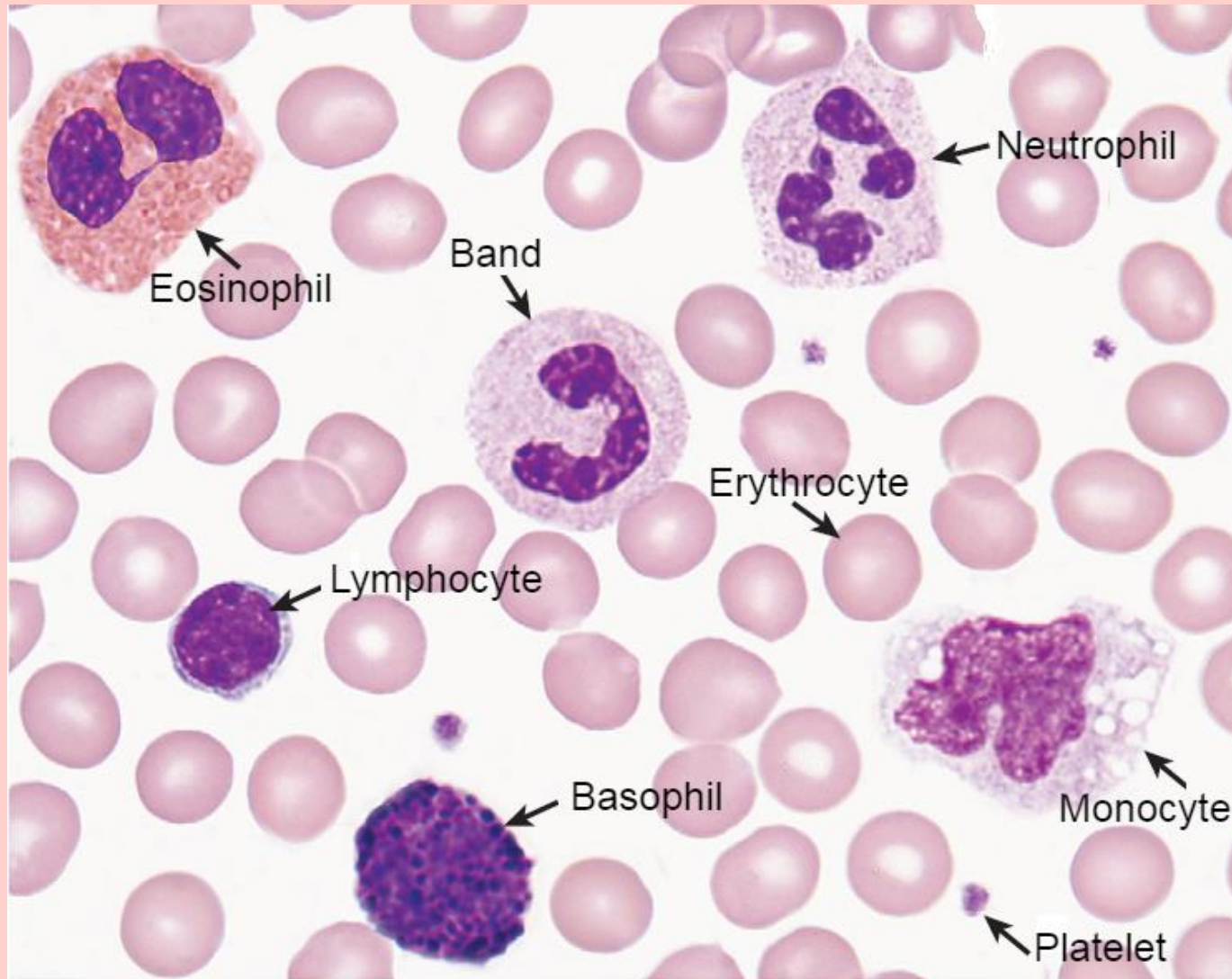
**A to H: Unacceptable peripheral blood films.**  
 Slide appearances associated with the most common errors.

- A** Chipped or rough edge on spreader slide.
- B** Hesitation in forward motion of spreader slide.
- C** Spreader slide pushed too quickly.
- D** Drop of blood too small.
- E** Drop of blood not allowed to spread across the width of the slide.
- F** Dirt or grease on the slide; may also be PB specimen elevated lipids.
- G** Uneven pressure on the spreader slide.
- H** Time delay; drop of blood began to dry prior to spread.



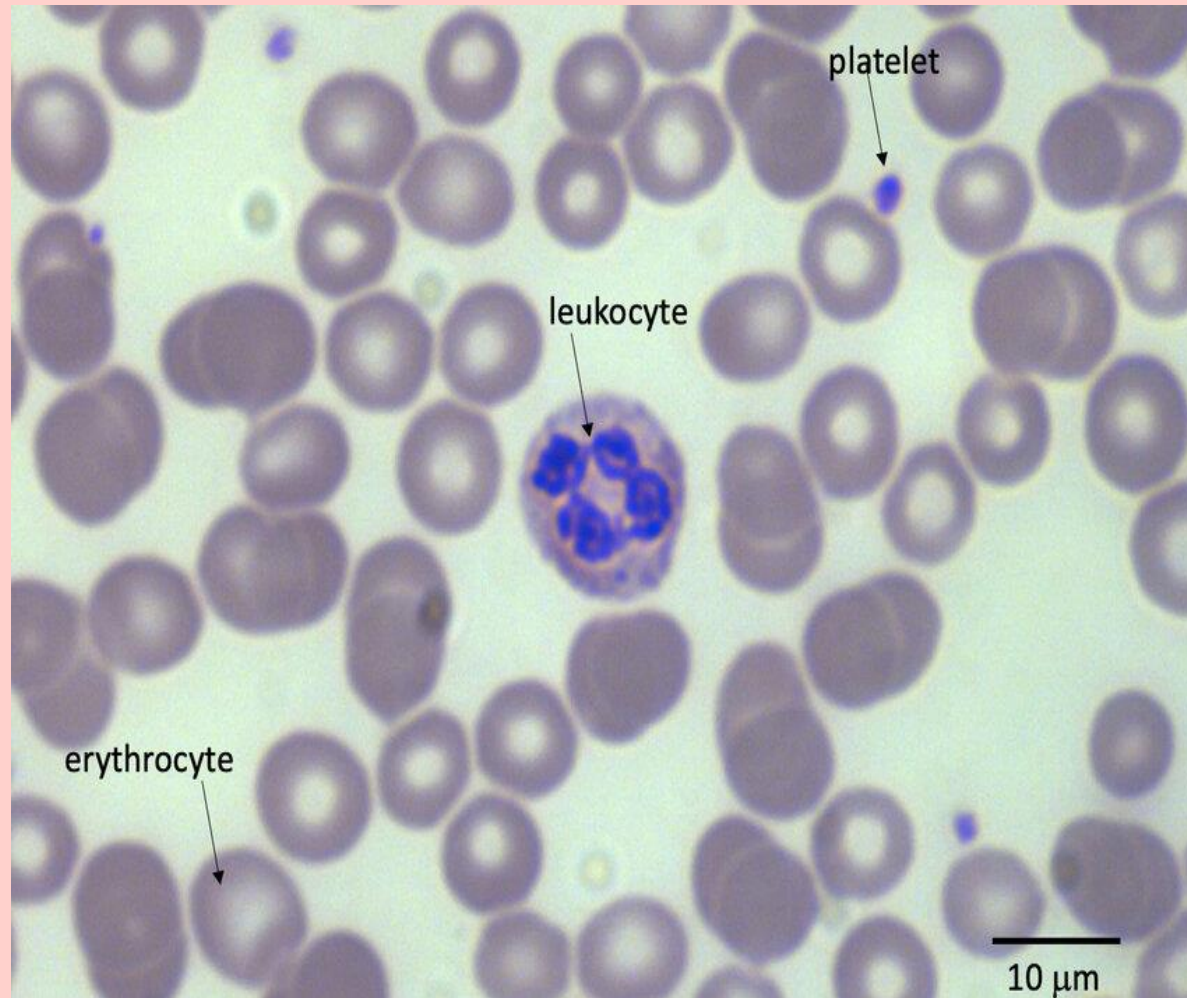
# Section 3: Quality Control of Staining

Proper staining is crucial for accurate morphological assessment. Staining quality directly impacts the visualization of cellular details essential for diagnosis.



## Wright-Giemsa Stain

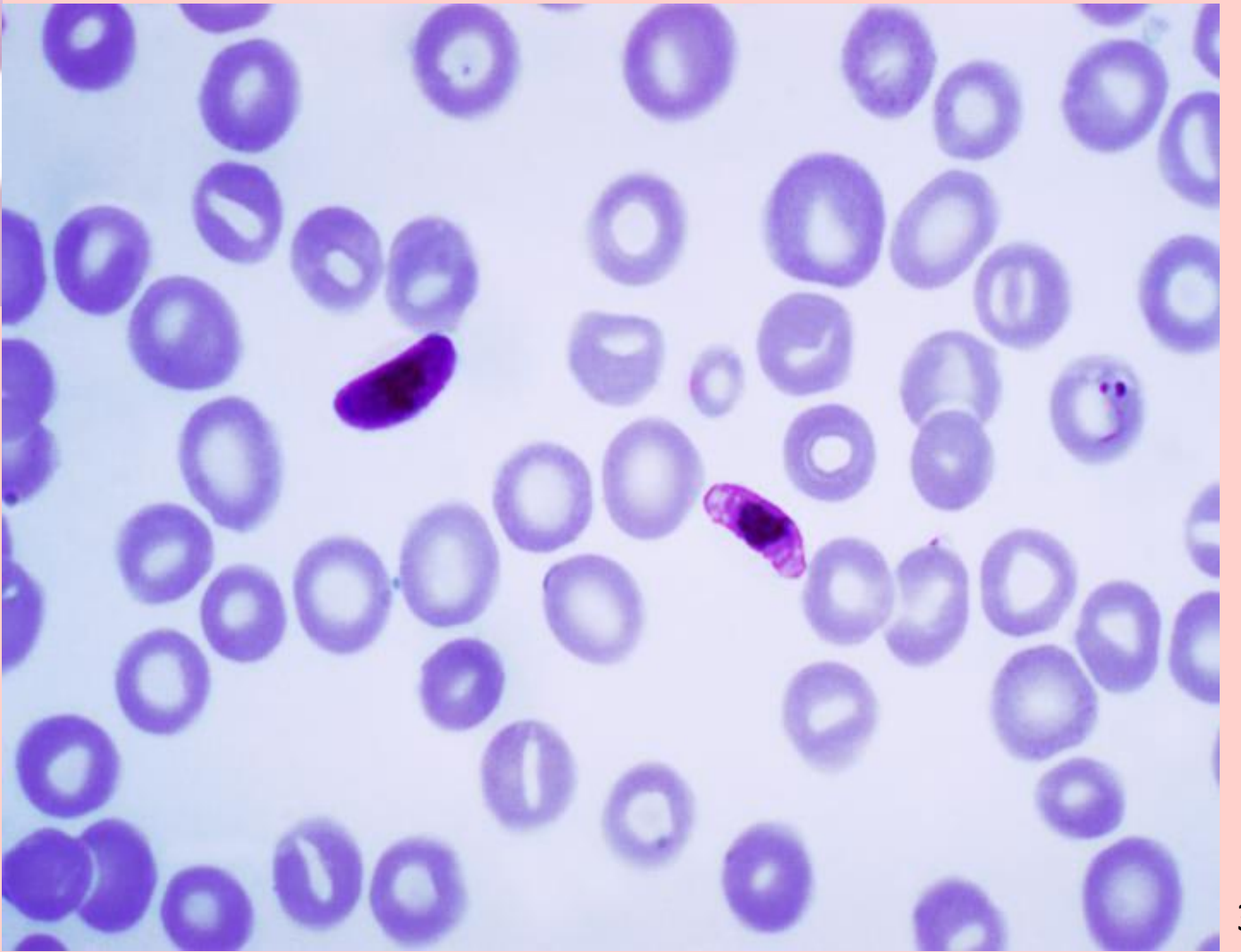
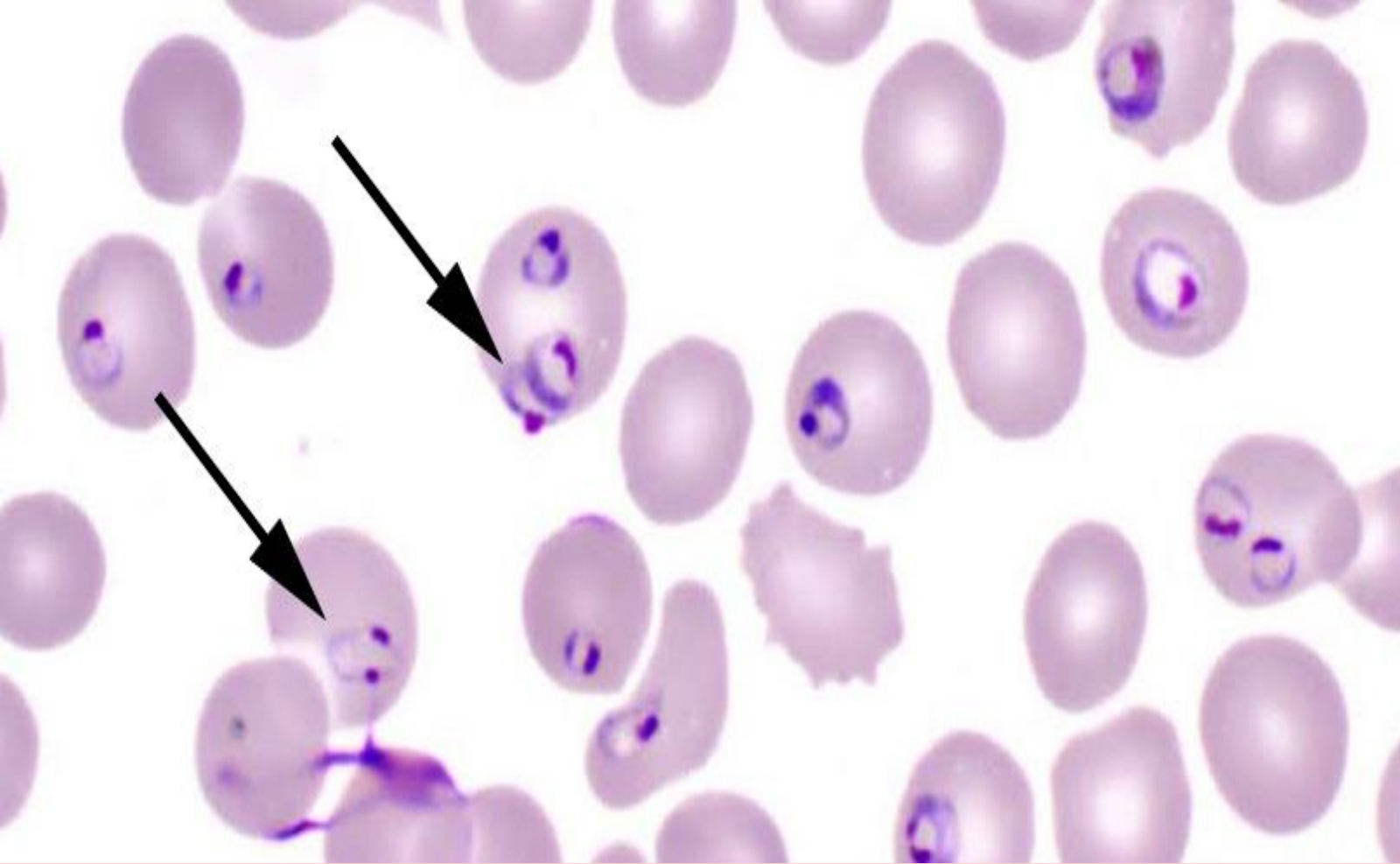
- Most commonly used for routine blood smear examination
- Provides excellent nuclear and cytoplasmic detail
- Allows clear visualization of granules and inclusions
- Optimal for WBC differential counting



## Giemsa Stain

- Preferred for parasite detection (especially malaria)
- Enhanced visualization of nuclear chromatin
- Superior for identifying Plasmodium species

⚠ Poor staining quality can lead to missed diagnoses of parasitic infections, misidentification of cell types, or failure to recognize clinically significant inclusions.



# Traditional QC for Staining

## pH Control

- Wright-Giemsa: Maintain pH at 6.8 ( $\pm 0.1$ )
- Giemsa: Maintain pH at 7.2 ( $\pm 0.1$ )
- Test buffer pH daily using calibrated meter
- Document pH values in QC logs

## Timing Standardization

- Wright-Giemsa: 5-10 minutes total staining time
- Giemsa rapid method: 10-15 minutes (10% solution)
- Giemsa slow method: 45-60 minutes (3-5% solution)
- Use calibrated timers to ensure consistency

## Expected Color Patterns

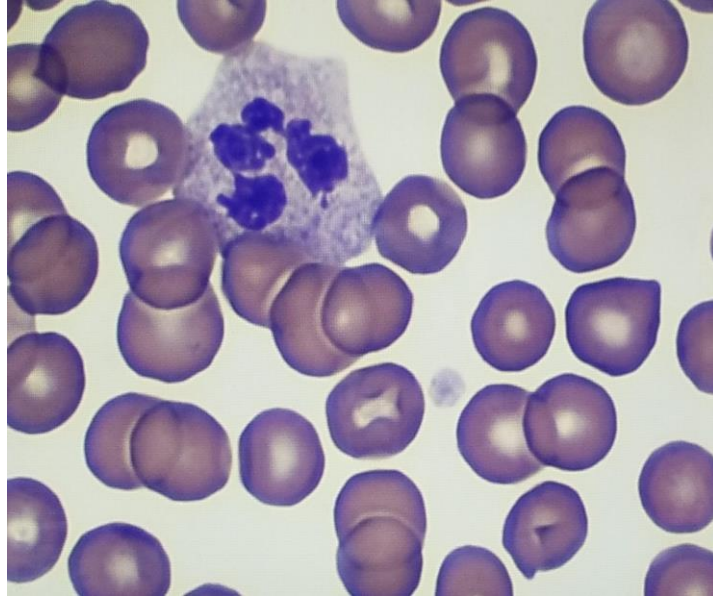
- RBCs: Pink to salmon-colored
- WBC nuclei: Purple to blue-purple
- Neutrophil granules: Lilac to light purple
- Eosinophil granules: Bright red-orange

## Control Procedures

- Stain one known control smear daily
- Include positive controls (e.g., malaria-positive for Giemsa)
- Filter stains daily through 0.45 $\mu$ m filter
- Store stains in dark bottles away from light

⊗ **Example:** High pH ( $>7.0$ ) with Wright-Giemsa makes everything appear overly blue, obscuring neutrophil granules and making eosinophils difficult to identify—adjust with buffer solution and retest.

# Common Staining Issues



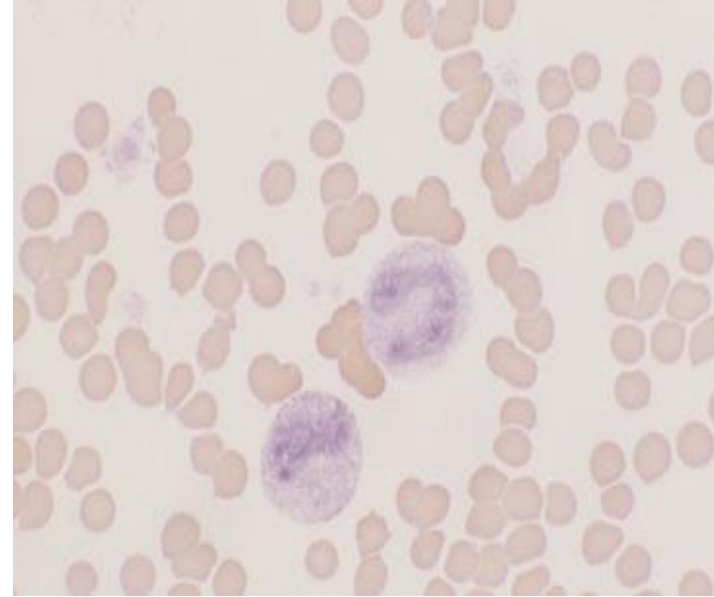
**Overly Blue Staining**

**Causes:**

- pH too high (>7.0 for Wright-Giemsa)
- Excessive staining time
- Insufficient buffer washing

**Solution:**

- Use precise timer to control staining
- Verify pH with calibrated meter
- Adjust buffer pH as needed



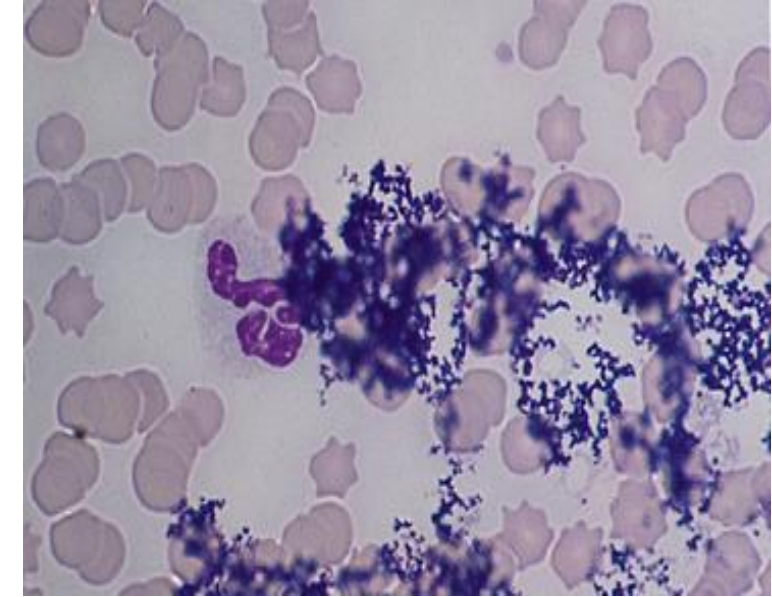
**Pale Staining**

**Causes:**

- Old or depleted stain
- pH too low (<6.4 for Wright-Giemsa)
- Insufficient staining time

**Solution:**

- Prepare fresh stain weekly
- Adjust pH to appropriate range
- Extend staining time slightly



**Precipitates**

**Causes:**

- Unfiltered stain
- Methanol evaporation
- Stain contamination

**Solution:**

- Filter stain daily through 0.45µm filter
- Keep containers tightly closed
- Use separate dropper for each solution

# Patient-Based QC for Staining



## Visual Quality Mean

Score nuclear clarity and granule definition (1-10 scale) from 30 consecutive patient smears

Significant drop in mean score (>15%) flags potential staining issues

Track scores over time to identify gradual deterioration

## Delta Check

Compare staining quality of sequential smears from the same patient

Unexplained differences in staining intensity or color balance indicate process variability

Particularly valuable when monitoring patients with regular follow-up testing

## PBRTQC

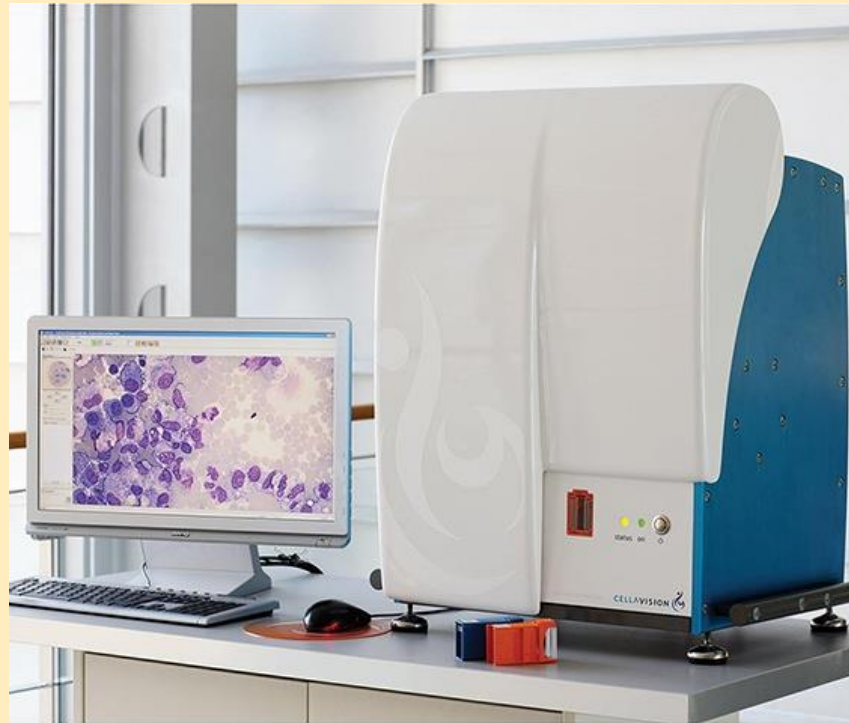
Implement digital image analysis with AI algorithms to quantify staining parameters

Set alerts for >10% deterioration in color intensity, contrast, or background clarity

Enables objective assessment of subjective visual characteristics

**Example:** A sudden drop in mean nuclear clarity score from 8.5 to 7.2 across 30 patient samples might indicate stain deterioration requiring filtration or replacement.

# Automation & AI in Peripheral Blood Smear Analysis



## Digital Slide Scanners

High-resolution imaging systems capture entire blood smears at multiple magnifications. These systems create permanent digital records for review, consultation, and QC purposes. Examples include CellaVision and Sysmex DI-60.

## AI-Assisted Morphology

Machine learning algorithms pre-classify blood cells and flag abnormalities. These systems can identify subtle morphological changes with high consistency and reduce inter-observer variability. Accuracy rates exceed 95% for routine cell classification.

## Workflow Improvements

Automated systems prioritize abnormal cases and focus human expertise where needed most. This approach significantly reduces review time, increases throughput, and improves result consistency while maintaining critical human oversight for complex cases.

These technologies enhance QC by providing objective metrics, standardized morphology assessment, and detailed documentation of cellular characteristics.



# Quality Control Summary

Area	Traditional QC	PBQC Methods	TEa / Limits (CLIA 2025)	EQA Requirement
PT/INR	2-level controls + Westgard rules	Patient mean, Delta check	±15%	≥3×/year
aPTT	2-level controls + Westgard rules	Moving average, Delta check	±15%	≥3×/year
Fibrinogen	2-level controls + Westgard rules	Moving average, Population data	±20%	≥3×/year
PBS	Smear quality, ≥100 WBC count	Morphology mean, Delta check	Qualitative assessment	≥4×/year
Staining	pH 6.8-7.2, time 5-10 min, daily control	Visual mean, Delta check	Qualitative assessment	Regular review

This approach combines traditional and patient-based QC methods to ensure reliable laboratory results.



# Final Recommendations for Laboratory Quality Excellence

## Implement Multi-Layered QC

Combine traditional QC with patient-based methods for comprehensive monitoring. Traditional QC provides baseline compliance, while PBQC detects subtle drifts cost-effectively, and PBRTQC enables real-time alerts through automation and AI.

## Documentation & Training

- Follow Standard Operating Procedures (SOPs) for all testing processes
- Conduct regular staff training through workshops and competency assessments
- Maintain detailed records for at least 2 years (longer where required by regulation)

## Continuous Improvement

- Review QC data regularly to identify trends before they become problems
- Participate in peer comparison programs to benchmark performance
- Integrate new technologies and methodologies as they become validated

**Remember: Quality is not just compliance—it's the foundation of patient care.**

The image features the words "THANK YOU!" in a vibrant, multi-colored, 3D sans-serif font. Each letter is a different color: 'T' is blue, 'H' is purple, 'A' is pink, 'N' is orange, 'K' is light orange, 'Y' is yellow, and 'O' is green. The letters have a slight shadow, giving them a three-dimensional appearance. The text is centered horizontally and surrounded by numerous small, scattered dots in various colors including blue, yellow, purple, orange, and pink, creating a festive and celebratory atmosphere.

THANK YOU!