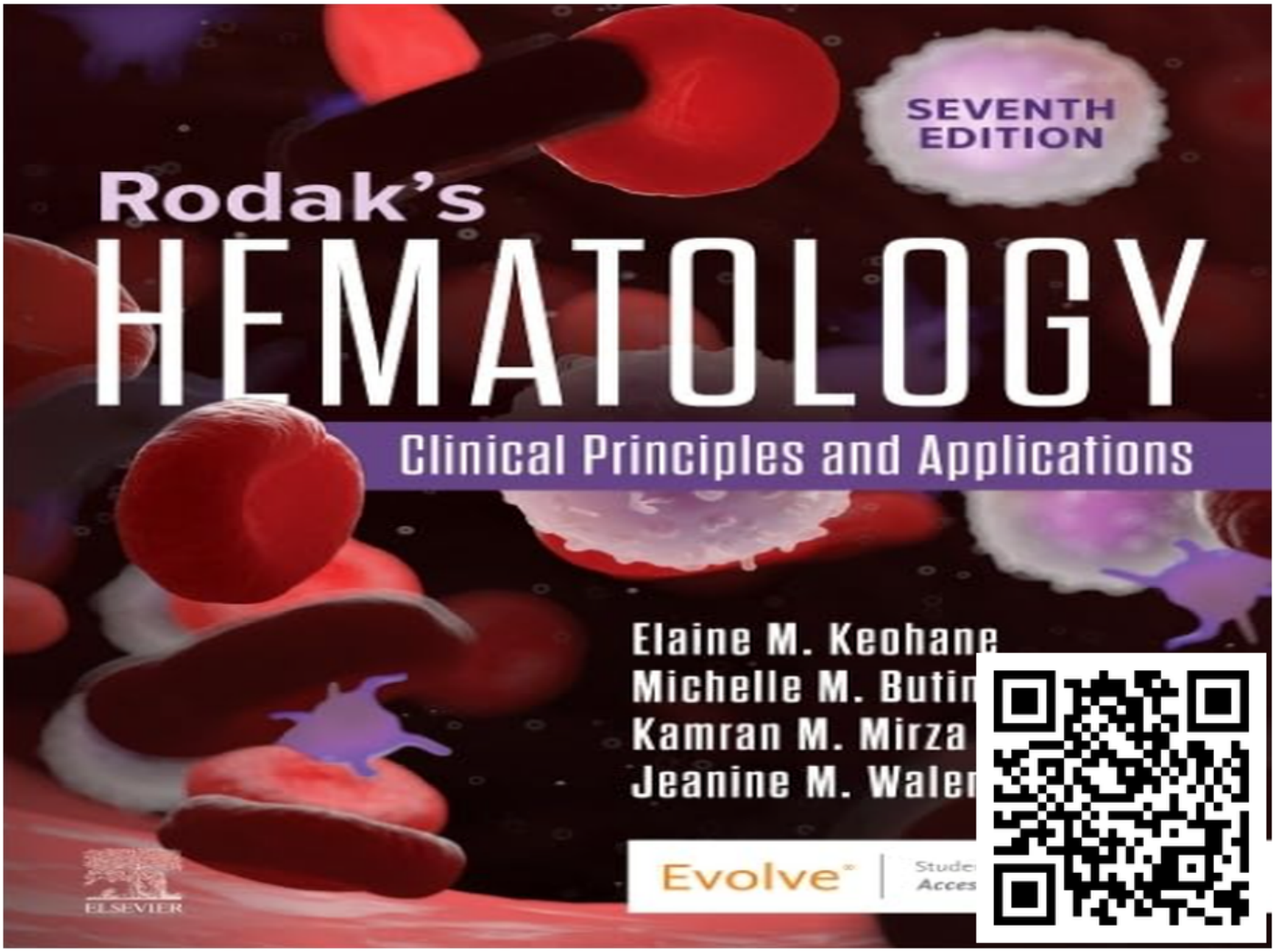

SEVENTH EDITION

Rodak's HEMATOLOGY

Clinical Principles and Applications

Elaine M. Keahane
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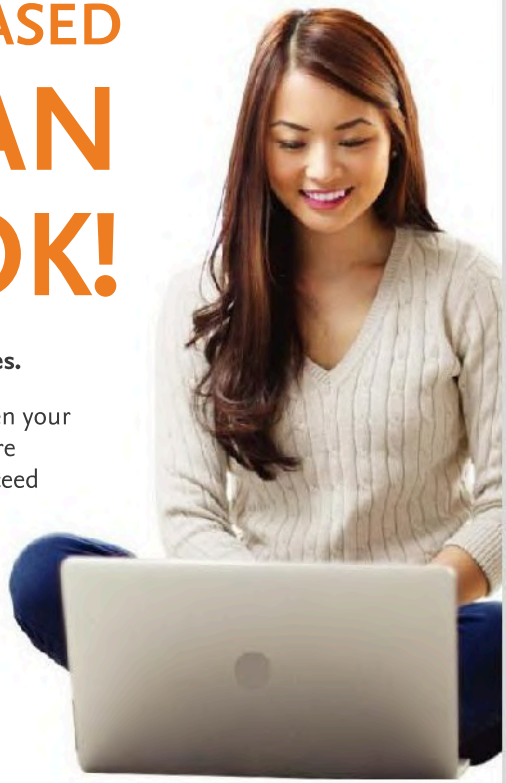

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Bernadette "Bunny" Beales Rodak, MS, MLS(ASCP)SH, Professor Emeritus of Pathology at Indiana University School of Medicine, died at the age of 70 on March 22, 2016. Bunny was the founding author and editor of *Hematology: Clinical Principles and Applications*, renamed *Rodak's Hematology: Clinical Principles and Applications* in 2016. For over 20 years and through five editions, she dedicated countless hours to this indispensable text while mentoring five coeditors and more than 50 authors. Bunny considered the combination of this textbook and the *Clinical Hematology Atlas,* coauthored with friend and colleague **Jacqueline Carr** through five editions, to be her greatest contribution to medical laboratory hematology. Bunny's work continues to inform and inspire a generation of medical laboratory practitioners and scholars as her textbook now offers its seventh edition.

Bunny authored numerous influential publications and conducted countless professional presentations. She chaired the American Society for Clinical Laboratory Science (ASCLS) Hematology and Hemostasis Scientific Assembly and went on to coordinate all of the ASCLS Scientific Assemblies. She was editor-in-chief of the ASCLS *Clinical Laboratory Science* journal and led an online expert team to answer consumer laboratory-related questions. She was a member of the ASCLS Education and Research Fund, which in 2016, endowed the Bernadette "Bunny" Rodak Memorial Scholarship. In 2013, the ASCLS awarded her their coveted Robin H. Mendelson Memorial Award, recognizing her achievements and contributions to medical laboratory science worldwide.

While an acknowledged innovator and role model, Bunny was readily available to students and colleagues. She put everyone at ease and, being humble, never revealed her long history of community service. All her acquaintances attest to her kind and helpful spirit. Bunny's colleagues miss her gracious smile and are honored to continue her work.

The Former and Current Editors

To my students for being great teachers, to my mentors for their guidance and support, and to Camryn, Riley, Harper, Stella, Jackie, Alana, Ken, and Jake for grounding me in the important things in life.
EMK

To my mentors, Kathryn Doig and Lynn Maedel, for sharing your inquisitiveness, enthusiasm, and vast knowledge of blood cells; your support and encouragement inspired me to take this exciting journey, and I am eternally grateful.
MMB

To John Anastasi and James Vardiman, for opening my eyes to the mystery, wonder, and beauty of hematopathology.
KMM

To my teachers, both formal and informal, for all this fascinating knowledge in the clinical laboratory sciences, which made possible my interesting career.
JMW

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PREFACE

The science of *clinical laboratory hematology* involves the analysis of normal and pathologic peripheral blood cells, hematopoietic (blood-producing) tissue, and hematopoietic cells in nonvascular body cavities such as cerebrospinal and serous fluids. Laboratory hematology also includes the analysis of the cells and coagulation proteins essential to clinical hemostasis. Hematology laboratory assay results are critical for diagnosis, prognosis, and monitoring treatment of primary and secondary hematologic and hemostatic disorders. Similarly, hematology and hemostasis test results are used to establish safety in the perioperative period, monitor treatments during surgical procedures, and monitor transfusion needs in trauma patients.

Rodak's Hematology: Clinical Principles and Applications systematically presents basic to advanced concepts to provide a solid foundation of healthy and pathologic states upon which readers can develop their skills in interpreting and correlating laboratory findings in anemias, hematologic malignancies, benign leukocyte disorders, and hemorrhagic and thrombotic conditions. It provides key features for accurate identification of normal and pathologic cells in blood, bone marrow, and body fluids. The focus, level, and detail of hematology, hematopathology, and hemostasis procedures, including their sources of error, along with the related clinical applications, interpretations, and testing algorithms are a highlight of this text.

The current practice of clinical laboratory hematology has been enhanced by profound changes as reflected in the numerous updates in the seventh edition of *Rodak's Hematology: Clinical Principles and Applications.* The seventh edition includes many improvements in the figures, tables, and boxes; significant updating of all chapters to include state-of-the-art content; major revisions in the chapters on automated blood cell analysis, acute leukemias, and hematology and hemostasis in selected populations (the last-mentioned including a new section on transgender populations); addition of a new chapter on patient safety; and addition of the thromboinflammatory reaction induced by COVID-19. Further, Michelle Montgomery Butina and Kamran M. Mirza are new coeditors, joining continuing editors, Elaine M. Keohane and Jeanine M. Walenga. Meticulous editing and attention to overall presentation of the material in the book add to the value of the seventh edition. Chapter highlights and new content are described below.

ORGANIZATION

Rodak's Hematology: Clinical Principles and Applications, seventh edition, is organized into 7 parts, 43 printed chapters, 4 e-chapters, and reference intervals for common laboratory assays conveniently located after the Index at the end of the book. Expanded appendices can be downloaded from the Evolve website allowing for easy access and searches of key abbreviations, formulas, glossary terms, and answers to case studies and review questions.

PART I: INTRODUCTION TO HEMATOLOGY

Chapter 1 previews the science of clinical laboratory hematology. Chapter 2 is new to the seventh edition and provides an overview of patient safety in hematology and hemostasis to ensure that the total testing process is safe, timely, efficient, equitable, patient centered, and effective. Chapter 3 provides comprehensive, updated coverage of quality assurance for laboratory testing, with enhanced sections on method evaluation, assay validation, multisite validation, and system-wide comparability.

PART II: BLOOD CELL PRODUCTION, STRUCTURE, AND FUNCTION

Chapters 4 and 5 include photomicrographs and figures to describe general cell structure and an updated section on selected cell processes, along with the morphologic and molecular details of hematopoiesis. Chapters 6, 10, and 11 discuss erythropoiesis, leukopoiesis, and megakaryopoiesis using numerous photomicrographs to demonstrate ultrastructure and microscopic morphology. Chapters 7 and 8 examine mature red blood cell metabolism, membrane and hemoglobin structure and function, and red blood cell senescence and destruction. Discussion of iron kinetics and laboratory assessment in Chapter 9 has been updated with new figures and coverage of systemic and cellular regulation of iron. Chapter 11 also includes a description of the function of platelets, detailing the primary hemostatic mechanisms of platelet adhesion, aggregation, and activation with updated information on the platelet proteome and the role of platelets in the inflammatory response.

PART III: LABORATORY EVALUATION OF BLOOD CELLS

Chapter 12 describes traditional (manual) clinical hematology laboratory procedures such as microscopy-based cell counts and hemoglobin and hematocrit determinations as well as point-of-care technology. Chapter 13 includes updated descriptions, principles of operation, and figures of the major, state-of-the-art automated blood cell analyzers. It also describes new analyzer parameters and their clinical use. The digital data management capabilities of these analyzers have revolutionized the way blood specimens for the complete blood count, differential count, and morphology assessment are analyzed and how test results are reported and interpreted. Chapter 14 describes peripheral blood film examination and the differential cell count correlation to the complete blood count. Chapter 15 follows up with bone marrow aspirate and biopsy collection, preparation, examination, and reporting.

PART IV: ERYTHROCYTE DISORDERS

Chapter 16 provides an overview of the anemias and describes cost-effective diagnostic approaches that integrate patient history, physical examination, and symptoms, with laboratory results for hemoglobin, red blood cell indices, reticulocyte count, and abnormal red blood cell morphology. Chapters 17 to 19 describe disorders of iron and DNA metabolism and bone marrow failure. Algorithms help the reader to distinguish types of microcytic and macrocytic anemias. Chapters 20 to 23 discuss hemolytic anemias due to intrinsic or extrinsic defects. Chapter 20 also includes detailed figures that explain extravascular and intravascular hemolysis and hemoglobin catabolism. Chapters 24 and 25 provide updates in pathophysiology, diagnosis, and treatment of the hemoglobinopathies and thalassemias, including the use of Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) technology.

PART V: LEUKOCYTE DISORDERS

The chapters in this section begin with nonmalignant disorders, followed by an introduction to hematologic neoplasms, three chapters discussing diagnostic methodologies, and finally chapters discussing the major categories of hematologic neoplasms.

Chapter 26 is updated with many excellent photomicrographs and summary boxes of nonmalignant leukocyte disorders manifested by the abnormal distribution or morphology of white blood cells. These include bacterial and viral infections, various systemic disorders, and benign lymphoproliferative disorders. Chapter 27 provides an introduction to hematologic neoplasms, including sections on classification, molecular pathogenesis, and general categories of treatment options. Chapter 28 describes flow cytometry and its diagnostic applications, including numerous scatterplots of normal and leukemic conditions. Chapter 29 covers molecular diagnostics, with many figures on basic molecular biology, real-time polymerase chain reaction (PCR), microarrays, and DNA sequencing, including next-generation sequencing. Molecular diagnosis has augmented or in many instances replaced long-indispensable laboratory assays. Chapter 30 provides details on traditional cytogenetic procedures for detection of quantitative and qualitative chromosome abnormalities and more sensitive methods such as fluorescence in situ hybridization (FISH) and genomic hybridization arrays. Chapters 31 to 34, with significant updating according to the 2022 World Health Organization classification, provide the latest pathophysiologic models for acute lymphoblastic and myeloid leukemias and myeloproliferative, myelodysplastic, and mature lymphoid neoplasms, with numerous full-color photomicrographs and illustrations. The chapters discuss traditional monitoring of leukemias and lymphomas at the cellular level; detection of minimal residual disease at the molecular level; and new targeted molecular, immunologic, and cellular therapies, which have dramatically improved survival.

PART VI: HEMOSTASIS AND THROMBOSIS

The chapters of this section begin with the mechanisms of normal hemostasis followed by the hemorrhagic disorders, thrombotic disorders, and anticoagulant therapies. Disorder-specific laboratory testing accompanies the clinical discussion of the disorder in each chapter. Routine coagulation tests and instrumentation are discussed in the chapters at the end of this section.

Chapter 35 describes in detail the plasma- and cell-based coagulation models including the interactions between primary hemostasis, secondary hemostasis, and fibrinolysis. Chapters 36 to 38 detail the hemorrhagic disorders including the diagnosis, management, and current therapies of acquired coagulopathies such as the acute coagulopathy of trauma and shock and inherited coagulopathies such as the hemophilias with a significant update on von Willebrand disease. Two chapters are devoted to quantitative and qualitative platelet defects as the cause of bleeding, with new and revised tables and figures. Chapter 39 describes the known mechanisms associated with venous thrombosis, pulmonary embolism, and arterial thrombosis. Detailed discussions of antiphopsholipid syndrome, disseminated intravascular coagulation, and heparin-induced thrombocytopenia, with its related vaccine-induced thrombocytopenia-thrombosis, are also provided. Thrombosis management in terms of prophylaxis and treatment, with current updates, is discussed in Chapter 40. The classical anticoagulants warfarin, heparin, and low-molecular-weight heparins are covered, along with new intravenous and oral thrombin and factor Xa inhibitor anticoagulants. Methods for monitoring each anticoagulant as used in various clinical settings as well as methods for monitoring the different classes of antiplatelet drugs are provided. Chapter 41 details coagulation specimen collection and handling and covers the traditional coagulation laboratory assays that assess platelet function, coagulation factors, and fibrinolytic parameters, including clot-based and chromogenic assays. Updates for new thrombin generation and viscoelastometry (VET) tests are included. Chapter 42 reviews the latest coagulation analyzers and point-of-care instrumentation for coagulation testing.

PART VII: HEMATOLOGY AND HEMOSTASIS IN SELECTED POPULATIONS

Chapter 43 underwent a major revision and provides valuable information on the hematology and hemostasis laboratory findings in the pediatric, pregnant, and geriatric populations as well as a new section on transgender populations, all correlated with information from previous chapters.

E-CHAPTERS

Four chapters that round out the details of good laboratory practice particular to hematology and hemostasis testing are provided in an online format. Chapter E1 provides the laboratory safety requirements to maintain a safe working environment to

prevent accidents and mitigate exposure to biological, chemical, electrical, and fire hazards. Chapter E2 describes the most up-to-date requirements for blood specimen collection from venipuncture and skin puncture. Chapter E3 describes the principles, care, and use of microscopes, including light, phase contrast, polarized light, darkfield, and fluorescent microscopy. Chapter E4 describes methods for analyzing normal and pathologic cells of cerebrospinal fluid, joint fluid, transudates, and exudates.

READERS

Rodak's Hematology: Clinical Principles and Applications is designed for medical laboratory scientists, medical laboratory technicians, and students and faculty of undergraduate and graduate educational programs in the clinical laboratory sciences and pathology. This text is also a helpful study guide for pathology and hematology-oncology residents and fellows and a valuable shelf reference for hematologists, pathologists, and hematology and hemostasis laboratory managers.

TEXTBOOK FEATURES

The outstanding value and quality of *Rodak's Hematology: Clinical Principles and Applications* reflect the educational and clinical expertise of its current and previous editors and authors who are each well known nationally, experienced, and respected in their field of expertise. The text is enhanced by nearly 700 full-color digital photomicrographs, figures, and line art. Detailed text boxes and tables clearly summarize important information. Reference intervals for common hematology, body fluid, and hemostasis laboratory assays are conveniently located after the Index at the end of the book.

Each chapter contains the following for enhanced pedagogical features:

- **Learning objectives** at all taxonomy levels in the cognitive domain
- One or two **case studies**, with open-ended discussion questions at the beginning of the chapter that stimulate interest and provide opportunities for application of chapter content in real-life scenarios
- A bulleted **summary** at the end of each chapter that provides a comprehensive review of essential material
- **Review questions** at the end of each chapter that correlate to chapter objectives and are in the multiple-choice format used by certification examinations

The Evolve website has multiple features **for the instructor**:

- A **test bank** that contains multiple-choice questions with rationales and cognitive levels
- **Instructor's manuals** for every chapter that contain key terms, objectives, outlines, and study questions
- **Learning objectives with taxonomy levels** to supplement lesson plans
- **Case studies** that have been updated and feature discussion questions and photomicrographs when applicable
- **PowerPoint presentations** for every chapter that can be used "as is" or as a template to prepare lectures
- An **image collection** that provides electronic files of all the chapter figures that can be downloaded into PowerPoint presentations

The Evolve website has important features for **the student and instructor**:

- **E-Chapters** on safety in the hematology laboratory, blood specimen collection, care and use of the microscope, and body fluid analysis
- Appendices that include an updated list of major abbreviations, commonly used formulas, answers to case studies and review questions, and an expanded glossary
- **Animations**

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The editors express their immense gratitude to Bernadette ("Bunny") Rodak, who laid the foundation for *Rodak's Hematology: Clinical Principles and Applications* with her expert writing, editing, detailed figures, and especially her contribution of almost 300 outstanding digital photomicrographs. Now in its seventh edition, we are honored to continue her work on this exceptional textbook. We sincerely thank George A. Fritsma for his significant contribution to this text as a coeditor in two editions and author of 10 chapters in previous editions, for coauthoring five chapters in the seventh edition, for sharing his immense expertise in hemostasis, and for his constant support and encouragement. We thank Kathryn Doig for her contributions as coeditor for the third edition and author of seven chapters in previous editions and for her tenaciousness, creativity, and care in updating three chapters coauthored in the seventh edition. We thank Larry J. Smith for his expertise and diligence as coeditor of the fifth edition and for authoring a chapter in previous editions. We thank Catherine N. Otto for her expertise and diligence as coeditor of the sixth edition and author of two chapters in previous editions, and authoring three chapters in the seventh edition. The editors also thank the many authors who have made and continue to make significant contributions to this work. All of these outstanding professionals have generously shared their time and expertise to make *Rodak's Hematology: Clinical Principles and Applications* into a worldwide educational resource and premier reference textbook for medical laboratory scientists and technicians as well as pathology and hematology practitioners, residents, and fellows.

We also express our appreciation to Elsevier, especially Sarah Vora, Rachel McMullen, and Kelly Skelton, whose professional support and reminders kept the project on track.

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Elaine M. Keohane
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CONTENTS

1

An Overview of Clinical Laboratory Hematology

*Elaine M. Keohane**

OUTLINE

The average human possesses 5 liters of blood. Blood transports oxygen from lungs to tissues; clears tissues of carbon dioxide; transports glucose, proteins, and lipids; and moves wastes to the liver and kidneys. The liquid portion is plasma, which, among many components, provides coagulation enzymes that protect vessels from trauma and maintain the circulation.

Plasma transports and nourishes blood cells. There are three categories of blood cells: red blood cells (RBCs), or *erythrocytes*; white blood cells (WBCs), or *leukocytes*; and platelets (PLTs), or *thrombocytes*.[1] Hematology is the study of these blood cells. By expertly staining, counting, analyzing, and recording the appearance, phenotype, and genotype of all three types of cells, the medical laboratory professional is able to predict, detect, and diagnose blood diseases and many systemic diseases that affect blood cells. Physicians rely on hematology laboratory test results to select and monitor therapy for these disorders; consequently, a complete blood count (CBC) is ordered on nearly everyone who visits a provider or is admitted to a hospital.

HISTORY

The first scientists, such as Athanasius Kircher in 1657, described "worms" in the blood, and Anton van Leeuwenhoek in 1674 gave an account of RBCs,[2] but it was not until the late 1800s that Giulio Bizzozero described platelets as "petite plaques."[3] The development of the Wright stain by James Homer Wright in 1902 opened a new world of visual blood film examination through the microscope. Although automated analyzers now differentiate and enumerate blood cells, Wright's Romanowsky-type stain (polychromatic, a mixture of acidic and basic dyes), and refinements thereof, remains the foundation of blood cell identification.[4]

In the present-day hematology laboratory, RBC, WBC, and platelet appearance is analyzed through automation or visually using 500× to 1000× light microscopy examination of cells fixed to a glass microscope slide and stained with *Wright* or *Wright-Giemsa stain* (Chapters 4, 13, 14, and E3). The scientific term for cell appearance is *morphology,* which encompasses cell color, size, shape, cytoplasmic inclusions, and nuclear condensation.

RED BLOOD CELLS

RBCs are anucleate, biconcave, discoid cells filled with a reddish protein, hemoglobin, which transports oxygen and carbon dioxide (Chapters 8 and 9). RBCs appear salmon pink and measure 7 to 8 μm in diameter with a zone of pallor that occupies one-third of their center (Figure 1.1A), reflecting their biconcavity (Chapters 6 and 7).

Since before 1900, physicians and medical laboratory professionals counted RBCs in measured volumes to detect anemia or polycythemia. *Anemia* means loss of oxygen-carrying capacity and is often reflected in a reduced RBC count or decreased RBC hemoglobin concentration (Chapters 16–25). *Polycythemia* means an increased RBC count reflecting increased circulating RBC mass, a condition that leads to hyperviscosity (Chapter 32).

*The author extends appreciation to George A. Fritsma, whose work in prior editions provided the foundation for this chapter.

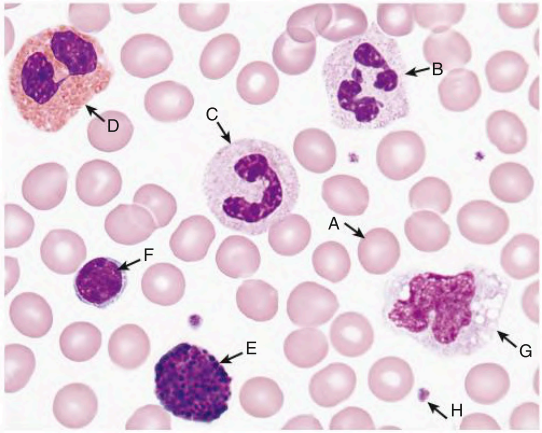

Figure 1.1 Composite of Cells Found in Peripheral Blood of Healthy Individuals. Erythrocyte (red blood cell, RBC) *(A)*; neutrophil (segmented neutrophil, NEUT, SEG, polymorphonuclear neutrophil, PMN) *(B)*; band (band neutrophil, BAND) *(C)*; eosinophil (EO) *(D)*; basophil (BASO) *(E)*; lymphocyte (LYMPH) *(F)*; monocyte (MONO) *(G)*; platelet (PLT) *(H)*. (Wright-Giemsa stain, ×1000.)

Historically, microscopists counted RBCs by carefully pipetting a tiny aliquot of whole blood and mixing it with 0.85% (normal) saline. Normal saline matches the osmolality of blood; consequently, the suspended RBCs retained their intrinsic morphology, neither swelling nor shrinking. A 1:200 dilution was typical for RBC counts, and a glass pipette designed to provide this dilution, the Thoma pipette, was used routinely until the advent of automation.

The diluted blood was transferred to a glass counting chamber called a hemacytometer (Figure 12.1). The microscopist observed and counted RBCs in selected areas of the hemacytometer, applied a mathematical formula based on the dilution and on the area of the hemacytometer counted (Chapter 12), and reported the RBC count in cells per microliter (µL, mcL; also called *cubic millimeter* [mm^3]), milliliter (mL; also called *cubic centimeter* [cc]), or liter (L).

Visual RBC counting was developed before 1900 and, although inaccurate, was the only way to count RBCs until the late 1950s, when automated particle counters became available in the clinical laboratory. The first electronic counter was patented in 1953 by Joseph and Wallace Coulter of Chicago, Illinois,[5] and today many high-quality automated blood cell analyzers exist using multiple complex technologies (Chapter 13). However, the Coulter principle of direct current electrical impedance is still used to count RBCs in many modern analyzers. Fortunately, the widespread availability of automated cell analysis has replaced visual RBC counting, although visual counting skills remain useful where automated analyzers are unavailable.

Hemoglobin, Hematocrit, and Red Blood Cell Indices

RBCs also are assayed for hemoglobin (HGB) concentration and hematocrit (HCT) (Chapter 12). Hemoglobin measurement relies on a weak solution of potassium cyanide and potassium ferricyanide (historically known as *Drabkin reagent).* An aliquot of whole blood is mixed with a measured volume of reagent, hemoglobin is converted to stable *cyanmethemoglobin* (hemiglobincyanide), and the absorbance or color intensity of the solution is measured in a spectrophotometer at 540 nm wavelength.[6] The color intensity is compared with that of a known standard and is mathematically converted to hemoglobin concentration. Modifications of the cyanmethemoglobin method are used in most automated applications, although some automated blood cell analyzers replace it with a formulation of the ionic surfactant (detergent) *sodium lauryl sulfate* to reduce environmental cyanide.

Hematocrit is the ratio of the volume of packed RBCs to the volume of whole blood and is manually determined by transferring blood to a plastic tube with a uniform bore, centrifuging, measuring the column of RBCs, and dividing by the total length of the column of RBCs plus plasma.[7] The normal ratio approaches 50%. Hematocrit is also called *packed cell volume* (PCV), the packed cells referring to RBCs. Often one can see a light-colored layer between the RBCs and plasma. This is the *buffy coat* and contains WBCs and platelets, and it is excluded from the hematocrit determination. The medical laboratory professional may use the three numerical results, RBC count, HGB, and HCT, to compute the RBC indices *mean cell volume* (MCV), *mean cell hemoglobin* (MCH), and *mean cell hemoglobin concentration* (MCHC) (Chapter 12). The MCV, although a volume measurement recorded in femtoliters (fL), reflects RBC diameter on a Wright-stained blood film. The MCHC, expressed in grams per deciliter (g/dL), reflects RBC staining intensity and amount of central pallor. The MCH in picograms (pg) expresses the mass of hemoglobin per cell and parallels the MCHC. A fourth RBC index, *red cell distribution width* (RDW), expresses the degree of *variation* in RBC volume. Extreme RBC volume variability is visible on the Wright-stained blood film as variation in diameter and is called *anisocytosis.* The RDW is based on the standard deviation of RBC volume and is routinely reported by automated blood cell analyzers (Chapter 13). In addition to aiding in diagnosis of anemia, RBC indices provide stable measurements for internal quality control of automated blood cell analyzers (Chapter 3). Sample reference intervals for RBC parameters can be found after the Index at the end of the book; these vary by age and sex (Chapter 43).

Medical laboratory professionals routinely use light microscopy at 500× or 1000× magnification to visually review RBC morphology, commenting on RBC diameter, color or hemoglobinization, and shape and the presence of cytoplasmic inclusions (Chapters 14 and 16). All these parameters—RBC count, HGB, HCT, indices, and RBC morphology—are employed to detect, diagnose, assess the severity of, and monitor the treatment of anemia, polycythemia, and the numerous systemic conditions that affect RBCs (Chapters 17–25 and Chapter 32). Automated blood cell analyzers are used in nearly all clinical laboratories to generate these data, although visual examination of the Wright-stained blood film is still essential to verify abnormal results.[8]

Reticulocytes

On the Wright-stained blood film, 0.5% to 2.5% of RBCs exceed the 7- to 8-µm average diameter and stain slightly blue-gray. These are *polychromatic (polychromatophilic)* erythrocytes, newly released from the RBC production site: the bone marrow (Chapters 5 and 6). Polychromatic erythrocytes are closely observed because they indicate the ability of the bone marrow to increase RBC production in anemia caused by blood loss or excessive RBC destruction (Chapters 20–24).

Methylene blue dyes, called *nucleic acid stains* or *vital stains,* are used to differentiate and count these young RBCs. Vital (or supravital) stains are dyes absorbed by live cells.[9] Young RBCs contain ribonucleic acid (RNA) and are called *reticulocytes* when the RNA is visualized using vital stains (Chapter 12). Counting reticulocytes visually by microscopy was (and remains) a tedious and imprecise procedure until the development of automated reticulocyte counting by the TOA Corporation (presently Sysmex) in the 1990s. Now all fully automated blood cell analyzers provide a relative reticulocyte percentage, an *absolute reticulocyte count,* and an especially sensitive measure of RBC production, the *immature reticulocyte fraction* (Chapter 13). However, it is still necessary to confirm automated analyzer counts visually from time to time, so medical laboratory professionals must retain this skill.

WHITE BLOOD CELLS

WBCs, or leukocytes, are a loosely related category of cell types dedicated to protecting their host from infection and injury (Chapters 5 and 10). WBCs are transported in the blood from their source, usually bone marrow or lymphoid tissue, to their tissue or body cavity destination. WBCs are so named because they are nearly colorless in an unstained cell suspension.

WBCs may be counted visually using a microscope and hemacytometer (Chapter 12). The technique is the same as RBC counting, but the typical dilution is 1:20, and the diluent is a dilute acid solution. The acid causes RBCs to *lyse* or rupture; without it, RBCs, which are 500 to 1000 times more numerous than WBCs, would obscure the WBCs. The WBC count reference intervals can be found after the Index at the end of the book. Visual WBC counting has been largely replaced by automated blood cell analyzers, but it is accurate and useful in situations in which no automation is available. Medical laboratory professionals who analyze body fluids such as cerebrospinal fluid or pleural fluid may employ visual WBC counting (Chapter E4).

A decreased WBC count is called *leukopenia,* and an increased WBC count is called *leukocytosis,* but the WBC count alone has modest clinical value. The microscopist must differentiate the categories of WBCs in the blood by using a Wright-stained blood film and light microscopy (Chapters 10 and 14). The types of WBCs found in peripheral blood in healthy individuals are as follows:

- Neutrophils (NEUTs, segmented neutrophils [SEGs], polymorphonuclear neutrophils [PMNs]) (Figure 1.1B). Neutrophils are phagocytic cells whose major purpose is to engulf and destroy microorganisms and foreign material, either directly or after they have been labeled for destruction by the immune system. The term *segmented* refers to their multilobed nuclei. The cytoplasm of neutrophils contains pink- or lavender-staining granules filled with bactericidal substances. An increase in neutrophils is called *neutrophilia* and often signals bacterial infection. A decrease is called *neutropenia* and has many causes, but it is often caused by certain medications or viral infections.
- Bands (BANDS, band neutrophils) (Figure 1.1C). Bands are slightly less mature neutrophils with a nonsegmented nucleus in a U or S shape. An increase in bands also signals bacterial infection and is customarily called a *left shift.*
- Eosinophils (EOs) (Figure 1.1D). Eosinophils are cells with round, bright orange-red cytoplasmic granules filled with proteins involved in immune system regulation. An elevated eosinophil count is called *eosinophilia* and often signals a response to allergy or parasitic infection.
- Basophils (BASOs) (Figure 1.1E). Basophils are cells with dark purple, irregular cytoplasmic granules that obscure the nucleus. The basophil granules contain histamines and various other proteins. An elevated basophil count is called *basophilia.* Basophilia is rare and often signals a hematologic disease.

  The distribution of eosinophils and basophils in blood is so small compared with that of neutrophils that the terms *eosinopenia* and *basopenia* are theoretical and not used. Neutrophils, bands, eosinophils, and basophils are collectively called *granulocytes* because of their prominent cytoplasmic granules, although their functions differ.
- Lymphocytes (LYMPHs) (Figure 1.1F). Lymphocytes comprise a complex system of cells that provide for host immunity. Lymphocytes recognize foreign antigens and mount *humoral* (antibody) and *cell-mediated* immune responses. On the Wright-stained blood film, most lymphocytes are nearly round, are slightly larger than RBCs, and have a round, condensed nucleus and a thin rim of nongranular cytoplasm. An increase in the lymphocyte count is called *lymphocytosis* and often is associated with viral infections. Reactive lymphocytes with characteristic morphology often accompany lymphocytosis (Chapter 26). An abnormally low lymphocyte count is called *lymphopenia* or *lymphocytopenia* and is often associated with drug therapy or immunodeficiency.
- Monocytes (MONOs) (Figure 1.1G). Monocytes are immature *macrophages* passing through the blood from their point of origin, usually the bone marrow, to a targeted tissue location. Macrophages are the most abundant cell type in the body, although monocytes comprise a minor component of peripheral blood WBCs. Macrophages occupy every body cavity; some are motile and some are immobilized. Their tasks are to identify and *phagocytize* (engulf and consume) foreign particles and assist the lymphocytes in mounting an immune response through the assembly and presentation of antigen *epitopes.* On the Wright-stained blood film, monocytes have a slightly larger diameter than other WBCs, blue-gray cytoplasm with fine azure granules, and a nucleus that is usually indented or folded. An increase in the number of

monocytes is called *monocytosis.* Benign monocytosis may be found in certain infections or in inflammation (Chapter 26). Medical laboratory professionals seldom document a decreased monocyte count, so the theoretical term *monocytopenia* is seldom used.

Leukemia is an uncontrolled proliferation of a clone of malignant WBCs. Leukemia may be chronic, for example, chronic myeloid leukemia or chronic lymphocytic leukemia, or acute, for example, acute myeloid leukemia or acute lymphoblastic leukemia (Chapter 27 and Chapters 31–34). Leukemias may involve any of the cell lines and are categorized by their respective immunophenotypes and genetic aberrations (Chapters 28–30). Some leukemias are more common in a specific age group; chronic lymphocytic leukemia is more prevalent in people older than 65 years, whereas acute lymphoblastic leukemia is the most common form of childhood leukemia (Chapters 31 and 34). Medical laboratory scientists participate in characterization of leukemias using Wright-stained bone marrow smears, flow cytometric immunophenotyping, molecular diagnostic technology, cytogenetics, and, occasionally, cytochemical staining (Chapter 15 and Chapters 28–30).

PLATELETS

Platelets, or thrombocytes, are true blood cells that maintain blood vessel integrity by initiating vessel wall repairs (Chapter 11). Platelets rapidly adhere to the surfaces of damaged blood vessels and form aggregates with neighboring platelets to plug the hole in the damaged vessels. Platelets are the major cells that control *hemostasis,* a series of cellular and plasma-based mechanisms that seal wounds, repair vessel walls, and maintain vascular patency (unimpeded blood flow) (Chapter 35). Platelets are only 2 to 4 µm in diameter, round or oval, anucleate, and slightly granular (Figure 1.1H). Their small size makes them appear insignificant, but they are essential to life and are extensively studied for their complex physiology. Uncontrolled platelet and hemostatic activation is responsible for deep vein thrombosis, pulmonary emboli, acute myocardial infarctions (heart attacks), cerebrovascular accidents (strokes), peripheral artery disease, and repeated spontaneous abortions (miscarriages) (Chapter 39).

The microscopist counts platelets employing the same technique used in counting WBCs on a hemacytometer, although a different counting area, diluent, and dilution are usually used (Chapter 12). Owing to their small volume, platelets are hard to distinguish visually in a hemacytometer, and phase microscopy provides for easier identification. Automated blood cell analyzers have largely replaced visual platelet counting and provide greater accuracy (Chapter 13). The reference interval for the platelet count can be found after the Index at the end of the book.

One advantage of automated blood cell analyzers is their ability to generate a mean platelet volume (MPV), which is unavailable through visual methods. The presence of predominantly larger platelets generates an elevated MPV value, which sometimes signals a regenerative bone marrow response to platelet consumption (Chapters 11 and 38).

Elevated platelet counts, called *thrombocytosis,* signal inflammation or trauma but convey modest intrinsic significance. *Essential thrombocythemia* is a rare malignant condition characterized by extremely high platelet counts and uncontrolled platelet production. Essential thrombocythemia is a life-threatening hematologic disorder (Chapters 32 and 38).

A low platelet count, called *thrombocytopenia,* is a common consequence of drug treatment and may be life-threatening. Because the platelet is responsible for normal blood vessel maintenance and repair, thrombocytopenia is usually accompanied by easy bruising and uncontrolled hemorrhage (Chapter 38). Thrombocytopenia accounts for many hemorrhage-related emergency department visits. Accurate platelet counting contributes to patient safety because it provides for the diagnosis of thrombocytopenia in many disorders or therapeutic regimens.

COMPLETE BLOOD COUNT

A CBC is performed on automated blood cell analyzers and includes the RBC, WBC, and platelet measurements indicated in Box 1.1. The medical laboratory professional may collect a blood specimen for the CBC, but a phlebotomist, nurse, physician assistant, physician, or patient care technician may also collect the specimen (Chapters 12, 41, and E2). No matter who collects a blood specimen, the medical laboratory professional is responsible for the integrity of the specimen and ensures that it is submitted in the appropriate anticoagulant and tube and is free of clots and hemolysis (red-tinted plasma indicating RBC damage). The specimen must be of sufficient volume because "short draws" result in incorrect anticoagulant-to-blood ratios. The specimen must be tested or prepared for storage within the appropriate time frame to ensure accurate analysis (Chapter 3) and must be accurately registered in the work list, a process known as specimen *accession.* Accession may be automated, relying on bar code or radiofrequency identification technology, thus reducing instances of identification error.

BOX 1.1 Basic Complete Blood Count Measurements Generated by Automated Blood Cell Analyzers

RBC Parameters	WBC Parameters
RBC count	WBC count
HGB	NEUT count: % and absolute
HCT	LYMPH count: % and absolute
MCV	MONO count: % and absolute
MCH	EO and BASO counts: % and absolute
MCHC	**Platelet Parameters**
RDW	PLT count
RETIC count	MPV

BASO, Basophil; *EO,* eosinophil; *HCT,* hematocrit; *HGB,* hemoglobin; *LYMPH,* lymphocyte; *MCH,* mean cell hemoglobin; *MCHC,* mean cell hemoglobin concentration; *MCV,* mean cell volume; *MONO,* monocyte; *MPV,* mean platelet volume; *NEUT,* segmented neutrophil; *PLT,* platelet; *RBC,* red blood cell; *RDW,* red cell distribution width; *RETIC,* reticulocyte; *WBC,* white blood cell.

Although all laboratory scientists and technicians are equipped to perform visual RBC, WBC, and platelet counts using dilution pipettes, hemacytometers, and microscopes, most laboratories employ automated blood cell analyzers to generate the CBC. Many blood cell analyzers also provide comments on RBC, WBC, and platelet morphology (Chapter 13). When one of the results from the blood cell analyzer is abnormal, the instrument provides an indication of this, sometimes called a *flag.* In this case, a reflex *blood film examination* is performed (Chapter 14).

The blood film examination (described next) is a specialized, demanding, and fundamental CBC activity. Nevertheless, if all blood cell analyzer results are within reference intervals, the blood film examination is usually omitted from the CBC. However, providers may request a blood film examination on the basis of clinical suspicion even when the analyzer results fall within their respective reference intervals.

BLOOD FILM EXAMINATION

To complete a blood film examination, the microscopist prepares a "wedge-prep" blood film on a glass microscope slide, allows it to dry, and fixes and stains it using Wright or Wright-Giemsa stain (Chapter 14). The microscopist visually performs an estimate of the WBC count (with the 40× or 50× objective at 400× or 500× magnification) and platelet count (with the 100× oil immersion objective at 1000× magnification) for comparison with their respective analyzer counts and investigates discrepancies. Next, the microscopist systematically reviews, identifies, and tabulates 100 (or more) WBCs to determine their percent distribution. This process is referred to as determining the *WBC differential* ("diff"). The WBC differential relies on the microscopist's skill, visual acuity, and integrity, and it provides extensive diagnostic information. Finally, the microscopist examines the morphology of WBCs, RBCs, and platelets by light microscopy for abnormalities of shape, diameter, color, or inclusions using 1000× magnification. Digital morphology recognition systems such as the CellaVision DM9600 (Chapter 14) automate the WBC, RBC, and platelet morphology assessment and WBC differential processes, but the medical laboratory professional or the hematopathologist is the final arbiter for all cell identification. Results of the CBC, including all automated blood cell analysis and blood film examination parameters and interpretive comments, are provided in paper or digital format for the provider's review, with abnormal results highlighted.

ENDOTHELIAL CELLS

Because they are structural and do not flow in the bloodstream, endothelial cells, the endodermal cells that form the inner surface of the blood vessel, are seldom studied in the hematology laboratory. Nevertheless, endothelial cells are important in maintaining normal blood flow, in tethering (decelerating) platelets during times of injury, and in enabling WBCs to escape from the vessel to the surrounding tissue when needed (Chapter 35). Increasingly refined laboratory methods are becoming available to assay and characterize the secretions of these important cells.

COAGULATION

Most hematology laboratories include a blood coagulation-testing department (Chapters 41 and 42). Platelets are a key component of hemostasis, as previously described; plasma coagulation is the second component (Chapter 35). The coagulation system employs a complex sequence of plasma proteins, some enzymes, and some enzyme cofactors to produce clot formation after blood vessel injury. Another six to eight enzymes exert control over the coagulation mechanism, and a third system of enzymes and cofactors digests clots to restore vessel patency, a process called *fibrinolysis.* Bleeding (Chapters 36–38) and clotting (Chapter 39) disorders are numerous and complex, and the coagulation section of the hematology laboratory provides a series of plasma-based and whole blood laboratory assays that assess these plasma proteins and their interactions with hematologic cells.

The medical laboratory professional focuses especially on blood specimen integrity for the coagulation laboratory because minor blood specimen defects, including clots, hemolysis, lipemia, plasma bilirubin, and short draws, render the specimen useless (Chapter 41). High-volume coagulation tests suited to the acute care facility include the platelet count and MPV as described earlier, *prothrombin time* and *partial thromboplastin time* (or activated partial thromboplastin time), *thrombin time* (or thrombin clotting time), *fibrinogen assay,* and *D-dimer* assay (Chapter 41). The prothrombin time and partial thromboplastin time are particularly high-volume assays used in screening profiles. These tests assess each portion of the coagulation pathway for deficiencies and are used to monitor anticoagulant therapy (Chapter 40). In addition to these high-volume screening assays, moderate-volume assays for specific hemostatic parameters, including clot-based assays, chromogenic substrate assays, and immunoassays, are available in specialized or tertiary care facilities. The specialized or tertiary care coagulation laboratory with its interpretive complexities attracts advanced medical laboratory scientists with specialized knowledge and communication skills.

ADVANCED HEMATOLOGY PROCEDURES

Besides performing the CBC, the hematology laboratory provides *bone marrow examinations, flow cytometry immunophenotyping, cytogenetic analysis,* and *molecular diagnostic assays.* Performing these tests may require advanced preparation or particular dedication by medical laboratory scientists with a desire to specialize.

Medical laboratory scientists assist physicians with bedside *bone marrow* collection, then prepare, stain, and microscopically review bone marrow smears (Chapter 15). Bone marrow *aspirates* and *biopsy specimens* are collected and stained to analyze nucleated cells that are the immature precursors to blood cells (Chapter 5). Cells of the *erythroid* series are precursors to RBCs (Chapter 6); *myeloid* series cells mature to form bands and neutrophils, eosinophils, basophils, and monocytes (Chapter 10); and *megakaryocytes* produce platelets (Chapter 11). Medical

laboratory scientists, clinical pathologists, and hematologists review Wright-stained aspirate smears for morphologic abnormalities, high or low bone marrow cell concentration, and inappropriate cell line distributions. For instance, an increase in the erythroid cell line may indicate bone marrow compensation for excessive RBC destruction or blood loss (Chapter 16 and Chapters 20–24). The biopsy specimen, enhanced by *hematoxylin and eosin* (H&E) staining, may reveal abnormalities in bone marrow architecture indicating leukemia, bone marrow failure, or one of a host of additional hematologic disorders. Results of examination of bone marrow aspirates and biopsy specimens are compared with CBC results generated from the peripheral blood to correlate findings and develop pattern-based diagnoses.

In the bone marrow laboratory, cytochemical stains may occasionally be employed to differentiate abnormal myeloid, erythroid, and lymphoid cells. These stains include *myeloperoxidase, Sudan black B, nonspecific and specific esterase, periodic acid-Schiff, tartrate-resistant acid phosphatase,* and *alkaline phosphatase* (Chapters 31 and 32). The cytochemical stains are time-honored tests that in most laboratories have been replaced by flow cytometry immunophenotyping, molecular diagnostic, and cytogenetic techniques (Chapters 28–30). Since 1980, however, *immunostaining* methods have enabled identification of cell lines by detecting lineage-specific antigens on the surface or in the cytoplasm of leukemia and lymphoma cells. An example of immunostaining is a visible dye that is bound to antibodies to CD42b, a membrane protein that is present in the megakaryocytic lineage and may be diagnostic for megakaryoblastic leukemia (Chapter 31).

Flow cytometers may be *quantitative,* such as clinical flow cytometers that have grown from the original Coulter principle, or *qualitative,* including laser-based instruments that have migrated from research applications to the clinical laboratory (Chapters 13 and 28). The former devices are automated clinical blood cell analyzers that generate the quantitative parameters of the CBC through application of electrical impedance and laser or light beam interruption. Qualitative laser-based flow cytometers are mechanically simpler but technically more demanding. Both qualitative and quantitative flow cytometers are employed to analyze cell populations by measuring the effects of individual cells on laser light, such as *forward-angle fluorescent light scatter* and *right-angle fluorescent light scatter,* and by *immunophenotyping* for cell membrane epitopes using monoclonal antibodies labeled with fluorescent dyes. The qualitative flow cytometry laboratory is indispensable to leukemia and lymphoma diagnosis.

Cytogenetics (Chapter 30), a time-honored form of chromosome analysis, examines hematopoietic cells in bone marrow aspirate to identify large numerical or structural abnormalities in chromosomes at the microscopic level of resolution, such as the Philadelphia chromosome, a reciprocal translocation between chromosomes 9 and 22 that is diagnostic in chronic myeloid leukemia, and t(15;17), a translocation between chromosomes 15 and 17 that is diagnostic in acute promyelocytic leukemia. Cytogenomic techniques evaluate whole genome DNA to identify small numerical or structural abnormalities in chromosomes at the submicroscopic level of resolution, such as gains or losses of minute amounts of DNA. Cytogenetic and cytogenomic analysis remains essential to the diagnosis and treatment of leukemia.

Molecular diagnostic techniques (Chapter 29), the fastest-growing area of laboratory medicine, enhance and even replace some of the advanced hematologic methods. Real-time polymerase chain reaction, microarray analysis, fluorescence in situ hybridization, and next-generation DNA sequencing systems are highly sensitive and specific methods that enable medical laboratory scientists to detect various chromosome abnormalities and gene mutations that confirm specific types of leukemia and lymphoma, establish their therapeutic profile and prognosis, and monitor the effectiveness of treatment.

ADDITIONAL HEMATOLOGY PROCEDURES

Medical laboratory professionals provide several time-honored whole blood methods to support hematologic diagnosis. The *glucose-6-phosphate dehydrogenase assay* phenotypically detects an inherited RBC enzyme deficiency causing episodic hemolytic anemia (Chapter 21). The sickle cell solubility screening assay and its follow-up tests, hemoglobin electrophoresis and high-performance liquid chromatography, are used to detect and diagnose sickle cell anemia and other inherited qualitative hemoglobin abnormalities and thalassemias (Chapters 24 and 25). One of the oldest hematology tests, the *erythrocyte sedimentation rate,* detects inflammation and roughly estimates its intensity (Chapter 12).

Finally, the medical laboratory professional reviews the cell counts, distribution, and morphology in body fluids other than blood (Chapter E4). These include cerebrospinal fluid, synovial (joint) fluid, pericardial fluid, pleural fluid, and peritoneal fluid, in which RBCs and WBCs may be present in disease and in which malignant cells that require specialized detection skills may be present. Analysis of nonblood body fluids is always performed with a rapid turnaround because cells in these environments rapidly lose their integrity. The conditions leading to a need for body fluid analysis are invariably acute.

QUALITY ASSURANCE AND QUALITY CONTROL

Medical laboratory professionals employ particularly complex quality control systems in the hematology laboratory (Chapter 3). Because of the unavailability of weighed standards, the measurement of cells and biological systems defies chemical standardization and requires elaborate calibration, validation, matrix effect examination, linearity, and reference interval determinations. An internal standard methodology known as the *moving average* also supports hematology laboratory applications.[10] Medical laboratory professionals in all disciplines compare methods through clinical efficacy calculations that produce clinical sensitivity, specificity, and positive and negative predictive values for each assay. They must monitor specimen integrity and test ordering patterns and ensure the integrity and delivery of reports, including numerical and narrative statements and reference interval comparisons. As in most branches of laboratory science, the hematology laboratory places an

enormous responsibility for accuracy, integrity, judgment, and timeliness on the medical laboratory professional.

SAFETY

Safety can be discussed in two contexts—laboratory safety and patient safety. *Laboratory safety* requires all medical laboratory professionals to maintain a safe working environment to prevent accidents and mitigate exposure to biological, chemical, electrical, and fire hazards (Chapter E1). Written safety plans, training programs, emergency management plans, and use of appropriate personal protective equipment (PPE) are critical in maintaining a safe laboratory environment.

Patient safety requires all health care professionals to work with each other and their patients and caregivers to improve the delivery of health care and reduce medical errors (Chapter 2). In 2001 the Institute of Medicine (IOM), now the National Academy of Medicine, specified six aims to improve health care delivery to ensure that it is safe, timely, efficient, equitable, patient-centered, and effective.[11] Further, in 2003 the IOM specified five core competencies for all health care professionals to achieve those aims: provide patient-centered care, work in interdisciplinary teams, employ evidence-based practice, apply quality improvement, and utilize informatics.[12] Medical laboratory professionals play a vital role in collaborating with other health care providers to improve the delivery of laboratory services and ensure that laboratory tests are appropriately ordered, accurately performed in a timely manner, appropriately interpreted by health care providers, and accurately applied to the individual patient in a clear, timely, equitable, and effective manner.

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2

Patient Safety in Hematology and Hemostasis

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OBJECTIVES

After completion of this chapter, the reader will be able to:

1. Define patient safety.
2. Summarize the content of the National Academy of Medicine reports on health care quality.
3. Define each of the six quality aims for patient safety in health care.
4. Give examples of each of the six quality aims in medical laboratory professional practice in hematology and hemostasis.
5. List the five essential competencies for health care professionals.
6. Give examples of use for each of the five health care professional competencies in medical laboratory practice in hematology and hemostasis.

OUTLINE

CASE STUDY

After studying the material in this chapter, the reader should be able to respond to the following case study. Answers can be found in Appendix C.

Several values were flagged on the complete blood count (CBC) as being below the reference interval from a patient identified as L.M. The CBC results were released to the electronic medical record and to the provider who ordered the CBC. After reviewing the test results, the provider called the clinical laboratory to ask why the CBC report did not include reference intervals for transgender individuals who are transitioning or who have completed their transition.

1. Identify which CBC parameters need separate reference intervals for transgender individuals.
2. Explain how this may impact treatment for this patient.
3. Identify the dimensions of patient safety affected in this situation.
4. Describe solutions (recommendations) to improve dimensions of patient safety.

Patient safety and its importance in providing quality health care and improving patient outcomes came to the forefront in 2000 when the Institute of Medicine (a component of the National Academies of Sciences, Engineering, and Medicine) published *To Err Is Human,* reporting that up to 98,000 people die each year as a result of an adverse event while hospitalized.[1] Since 2000 the Institute of Medicine, now referred to as the National Academy of Medicine (NAM), has published multiple reports in their Quality Chasm Series, defining health care quality and its dimensions, identifying competencies for all health care practitioners (including medical laboratory professionals), and providing recommendations for improving diagnoses.[1-3] Although health care delivery systems have adopted quality improvement and other processes to reduce errors in delivery, and health care professional educational programs have incorporated curricula in patient safety competencies,

medical errors still occur every day in every delivery setting in the United States.[3] The importance of professionals (medical laboratory professionals) involved in the health care diagnostic process was a key outcome of the 2015 NAM report *Improving Diagnosis in Health Care*.[3] This chapter introduces the reader to critical patient safety concepts needed for effective medical laboratory science practice.

DEFINITION OF PATIENT SAFETY

The term *patient safety* is an all-encompassing term that includes all aspects of delivering health care; it is more than just ensuring that a patient does not fall while in the hospital. Patient safety is defined by the NAM as "freedom from accidental injury: avoidance, prevention, and amelioration of adverse outcomes or injuries stemming from the process of care."[1] Adverse outcomes that may result from the laboratory testing process include false-positive and false-negative test results; missed and delayed diagnoses; or missed, delayed, or inappropriate treatment. Injuries from the laboratory testing process can include hematomas or nerve damage following venipuncture. From a broader perspective, though, patient safety is related to many more aspects of laboratory practice.

DEFINITION OF HEALTH CARE QUALITY

Following *To Err Is Human*, the subsequent NAM report (*Crossing the Quality Chasm*) detailed the gap between the current US health care system and a system delivering ideal health care, suggesting how health care professionals might move "across the chasm" from a flawed system to a high-quality system. This report defines health care quality as "the degree to which health services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge."[2] Based on this definition, the NAM focuses on both *safety* and *quality* in the outcome of health care for the patient. This may seem intuitive in the 21st century; however, until the early 2000s, evaluation of health care quality focused on meeting accreditation standards such as those from The Joint Commission (for health care organizations) and the College of American Pathologists (for clinical laboratories), which placed a significant focus on the analytical phase of the Total Testing Process in the clinical laboratory (detailed in the following section). Medical laboratory professionals have used quality control and proficiency testing to evaluate analytical quality since the middle of the 20th century. With the changing focus on the patient and the outcome of their care, medical laboratory professionals are now obligated to evaluate and improve the quality of the entire testing process.

TOTAL TESTING PROCESS IN THE CLINICAL LABORATORY

The Total Testing Process in the clinical laboratory is a 3-phase, 11-step process (Figure 2.1). The process begins with the *preanalytical* (also called *preexamination*) *phase* that includes a clinical question ("Does the patient have this or that condition?"), followed by identifying the laboratory test to order, and then ordering it.[4] The next step involves collecting the specimen and transporting it to the medical laboratory.[4] The *analytical* (*examination*) *phase* begins with preparing the specimen for analysis, followed by analysis of the specimen, and then verification of the test results.[4] The *postanalytical (postexamination) phase* begins with reporting the test results to the provider, who then answers the clinical question and takes action that influences patient care.[4] Examples of outcomes of clinical laboratory testing include accurate, inaccurate, delayed, or no diagnosis achieved, or accurate, inaccurate, delayed, or no treatment employed. A key element of the Total Testing Process is the importance of *thinking* by the provider (to order the laboratory test and interpret the results within the context of the patient's symptoms) and the medical laboratory professional (to consult with providers on test selection and test result interpretation), described as the brain-to-brain loop.[5,6]

SIX AIMS OF HEALTH CARE QUALITY

The second report in the NAM Quality Chasm Collection, *Crossing the Quality Chasm,* identified *six aims or dimensions of health care quality*: safe, effective, efficient, timely, patient-centered, and equitable (Table 2.1).[2] These six dimensions of health care quality are important because they apply to all aspects of the health care delivery system, and their definitions identify a standard to measure quality. Each of the quality aims can be applied to medical laboratory professional practice in general and to the hematology and hemostasis laboratory specifically, as will be discussed in this chapter. When medical laboratory professionals focus on patient safety and health care quality goals, patients are more likely to avoid adverse outcomes of health care delivery, including errors in diagnosis; delays in treatment; unnecessary testing; and adverse events, such as death, misdiagnosis, mistreatment, and disability. Patient safety and reducing harm to patients requires attention to all six quality aims.

Safe Hematology and Hemostasis Testing

Safe health care is defined as "avoiding harm to patients from the care that is intended to help them."[2] Adverse events and medical errors are serious events that result in harm to patients and care that is unsafe. Laboratory testing services are not immune to errors or adverse events. One outcome of a delay in test results is a delay in diagnosis that leads to delay in treatment, lack of treatment, impairment, or death. Best practices in medical laboratory patient safety ensure that each patient receives the right test for their condition, at the right time, with accurate test results that provide information for the best outcome.

Errors or defects in the other five dimensions of health care affect safe laboratory testing. Patients incur harm if the wrong laboratory test is ordered, if the venipuncture to collect their blood specimen is performed inaccurately, or if the provider does not accurately interpret the test results or makes an inaccurate diagnosis based on the test results. Patients may incur harm if unnecessary laboratory tests are ordered and performed, laboratory test results are not available in a timely manner to

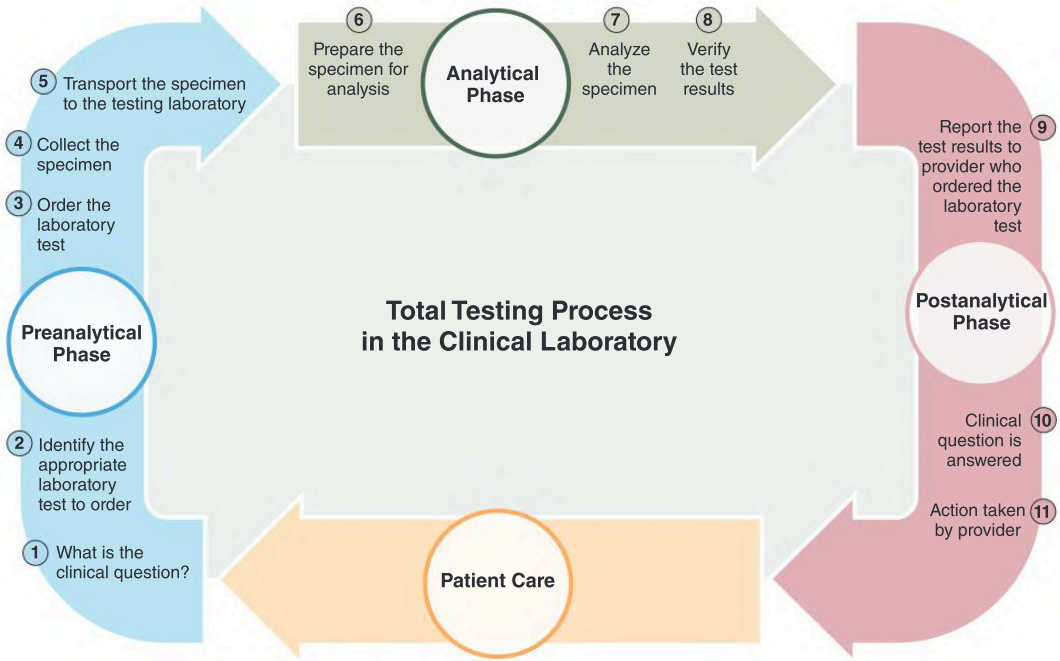

Figure 2.1 Total Testing Process in the Clinical Laboratory. Three phases and 11 steps in the Total Testing Process are depicted. The process begins with the preanalytical phase and flows through the analytical and then postanalytical phases to provide patient care. (Modified from Schumacher, G. E., & Barr, J. T. [1998]. Total testing process applied to therapeutic drug monitoring: impact on patient outcomes and economics. *Clin Chem*, *44*, 370–374.)

TABLE 2.1 Quality Aims to Evaluate and Improve Patient Safety in Health Care

Quality Aim	Definition
Safe	"avoiding injuries to patients from the care that is intended to help them."
Effective	"providing services based on scientific knowledge to all who could benefit and refraining from providing services to those not likely to benefit (avoiding underuse and overuse, respectively)."
Efficient	"avoiding waste, including waste of equipment, supplies, ideas, and energy."
Timely	"reducing waits and sometimes harmful delays for both those who receive care and those who give care."
Patient-centered	"providing care that is respectful and responsive to individual patient preferences, needs, and values and ensuring that patient values guide all clinical decisions."
Equitable	"providing care that does not vary in quality because of personal characteristics such as gender, ethnicity, geographic location, and socioeconomic status."

From Institute of Medicine Committee on Quality of Health Care in America. (2001). *Crossing the Quality Chasm: A New Health System for the 21st Century*. Washington, DC, The National Academy Press, pp. 5–6.

diagnose or treat a condition, the patient's input is not considered, or the patient does not have access to clinical laboratory testing.

In the preanalytical phase of testing, specimens for hematology and hemostasis testing must be appropriately collected from an accurately identified patient (Chapter E2). It is standard practice in all aspects of health care delivery to require two patient identifiers (e.g., first and last name and birth date) before any interaction or procedure, yet specimens are still collected from incorrectly identified patients, and specimens that were collected properly are mislabeled. This can lead directly to patient harm if test results from misidentified specimens are reported using the wrong patient's name.

Defects in specimen integrity (clotted, hemolyzed, incorrect anticoagulant, or insufficient quantity) affect the ability to analyze hematology and hemostasis specimens. Given that hematology and hemostasis tests require anticoagulated whole blood specimens, a clotted specimen cannot be tested, and it must be recollected (Chapters 12 and 41). An unacceptable specimen submitted for analysis is an inefficiency requiring recollection of the specimen at the minimum and no diagnosis or treatment if the specimen is not recollected and analyzed at the worst. Thus

TABLE 2.2 Recommendations From *Choosing Wisely**

Recommendation	Source
"Don't perform repetitive CBC and chemistry testing in the face of clinical and lab stability."	SHM-AHM
"Don't order an erythrocyte sedimentation rate (ESR) to look for inflammation in patients with undiagnosed conditions. Order a C-reactive protein (CRP) to detect acute phase inflammation."	ASCP
"Avoid using hemoglobin to evaluate patients for iron deficiency in susceptible populations. Instead use ferritin."	ASCLS
"Do not order red blood cell folate levels at all. In adults, consider folate supplementation instead of serum folate testing in patients with macrocytic anemia."	ASCP
"Do not perform peripheral blood flow cytometry to screen for hematological malignancy in the settings of mature neutrophilia, basophilia, erythrocytosis, thrombocytosis, isolated anemia, or isolated thrombocytopenia."	ASCP
"Avoid routine prothrombin time (PT) and partial thromboplastin time (PTT, APTT) pre-operative screens on asymptomatic patients, use instead a history-based bleeding assessment test."	ASCLS
"Don't test vitamin K levels unless the patient has an abnormal international normalized ratio (INR) and does not respond to vitamin K therapy."	ASCP
"Don't test or treat for suspected heparin-induced thrombocytopenia (HIT) in patients with a low pre-test probability of HIT."	ASH
"Don't treat patients with immune thrombocytopenic purpura (ITP) in the absence of bleeding or a very low platelet count."	ASH
"Don't order a factor V Leiden (FVL) mutation assay as the initial test to identify a congenital cause for a thrombotic event. First, order a phenotypic activated protein C resistance (APCR) ratio assay."	ASCLS
"Do not test for protein C, protein S, or antithrombin (ATIII) levels during an active clotting event to diagnose a hereditary deficiency because these tests are not analytically accurate during an active clotting event."	ASCP
"Do not order a protein S activity assay for measuring protein S function. Instead order free protein S antigen."	ASCLS

*These tests and their clinical applications are discussed in the chapters of this text.
ASCLS, American Society for Clinical Laboratory Science; *ASCP,* American Society for Clinical Pathology; *ASH,* American Society of Hematology; *CBC,* complete blood count; *SHM-AHM,* Society of Hospital Medicine-Adult Hospital Medicine.
Data from ABIM Foundation: *Choosing Wisely*. https://www.choosingwisely.org/. Accessed October 14, 2022.

it is important to ensure that specimens are recollected for those situations in which the original specimen was inadequate.

Effective Hematology and Hemostasis Testing

Effective health care is defined as "providing services based on scientific knowledge to all who could benefit and refraining from providing services to those not likely to benefit."[2] This means that medical laboratory professionals focus on providing appropriate laboratory tests and limit the use of laboratory tests that are not beneficial to the patient's condition. Effective laboratory testing requires understanding which laboratory tests are appropriate for specific diseases and their sequential use, communicating that information to providers, and incorporating test ordering guidelines into laboratory information systems. Ensuring that laboratory tests are used effectively requires employing evidence-based laboratory medicine and working with other health care professionals to incorporate and use the best laboratory tests for each disease process.

Identifying appropriate use of laboratory testing is a critical component of providing effective laboratory testing services. An example of a program that lists recommendations for both providers and patients is *Choosing Wisely*, sponsored by the American Board of Internal Medicine (ABIM) Foundation and supported by numerous professional organizations (Table 2.2). *Choosing Wisely* publishes peer-reviewed recommendations for testing supported by evidence.[7] Two examples related to hematology and hemostasis submitted by the American Society for Clinical Laboratory Science (ASCLS) recommend ordering a free protein S antigen to measure protein S function instead of a protein S assay (Chapter 39) and using ferritin to evaluate susceptible patients for iron deficiency instead of a hemoglobin level (Chapter 17).[8]

Efficient Hematology and Hemostasis Testing

Efficient laboratory testing is defined as "avoiding waste, including waste of equipment, supplies, ideas and energy."[2] An efficient laboratory testing process is one that has no defects: the specimen is appropriately collected, it is transported to the medical laboratory in a timely manner, the analysis is accurately performed, and the test results are sent to the provider in a timely manner. There is waste and inefficiency any time there is a problem with specimen integrity (clotted ethylenediaminetetraacetic acid specimen for a CBC or an inadequately filled sodium citrate tube for a prothrombin time) (Chapters 12 and 41). The integrity of each specimen is the responsibility of medical laboratory professionals, regardless of which member of the health care team collects the specimen. Thus the medical laboratory professional is responsible for educating other health care professionals on specimen collection methods and how defects in specimen collection affect patient care.

Beyond analyzing each specimen in an efficient manner, appropriate test utilization is an important goal for medical laboratory professionals. Inappropriate laboratory testing includes overuse, underuse, and misuse. In the hematology laboratory, a common example of overuse is a daily CBC for inpatients with no sign of bleeding or other hemodynamic instability. Overuse is both inefficient and ineffective, as well as unpleasant for the patient. Underuse is equally ineffective; ordering a test that provides diagnostic clarity, for example, allows correct treatment to be started more quickly. Testing misuse might be an order for the wrong test, for example, a factor X assay instead of

anti-factor Xa (Chapters 40 and 41), or the misinterpretation of results from a correctly ordered test, for example, ordering iron studies for a patient with a mean cell volume of 125 fL (Chapters 17 and 18).

Timely Hematology and Hemostasis Testing

Timely laboratory testing is defined as "reducing waits and sometimes harmful delays for both those who receive and those who give care."[2] Medical laboratory professionals have been measuring the turnaround time for many laboratory test results since the inception of the profession. Turnaround time is generally considered to be the time elapsed from the test order to the test report, but there is little consistency as to the specifics: Should the measured time start when the test order is placed or when the specimen reaches the laboratory? What is the end of the process—when the result is released or when action is taken with the patient? If only analytical time is tracked, then other phases of the Total Testing Process are not considered. This approach can overlook factors that are important for patients who are waiting in the emergency department or for other health care professionals who need information about the patient. Even though the preanalytical and postanalytical phases of testing involve nonlaboratory personnel, oversight of these phases is still a responsibility of the medical laboratory professional. In the hematology laboratory in particular, results of the CBC are often used with other tests as the basis for decisions about diagnosis, treatment, and hospital admission.

Patient-Centered Hematology and Hemostasis Testing

The definition of patient-centered laboratory testing services is "providing care that is respectful of and responsive to individual preferences, needs, and values and ensuring that patient values guide all clinical decisions."[2] Information is a critical component of delivering patient-centered care. Medical laboratory professionals should provide patients with information to prepare for laboratory tests (such as instructions for collecting fasting blood specimens or an explanation of the venipuncture procedure with information for care afterward) and to understand testing (e.g., reasons for genetic testing). Information should be written at an appropriate reading level for patients and available in multiple languages for patients who are not literate in English. Information may be provided as a document distributed to the patient in the phlebotomy waiting area or on the laboratory's website. Patient-centered service also requires communicating in a manner that meets individual preferences, such as addressing patients using their preferred pronouns and name.

Equitable Hematology and Hemostasis Testing

The definition of equitable laboratory testing services is "providing care that does not vary in quality because of personal characteristics such as gender, ethnicity, geographic location, and socioeconomic status."[2] Equitable health care, including laboratory testing, is influenced by social determinants of health. Social determinants of health are "conditions in the places where people live, learn, work, and play that affect a wide range of health and quality of life risks and outcomes."[9] Social determinants of health play a significant role in the differences in individual health status.[10] Examples of social determinants of health include access to health care (e.g., access to health insurance, living in a rural or urban location, availability of transportation), quality of health care (e.g., disparities in the delivery of care, lack of health literacy, language barriers), social and economic factors (e.g., degree of trust in the health care system, cultural beliefs regarding medical care, employment, and education level), physical environment (e.g., air and water quality, community safety, type of housing), and individual behaviors (e.g., use of tobacco, alcohol, or illicit drugs, diet, and exercise).[11]

Increasing equitable laboratory testing services for hematology and hemostasis testing (in fact, all laboratory testing) requires focusing on improving testing from the patient's perspective instead of the provider's habit or convenience. The hours of operation for phlebotomy services are one system perspective to consider for improving equitable access to laboratory testing services. Expanding the hours that phlebotomy services are available to include early morning and evening hours as well as weekends increases access to laboratory testing services to individuals who cannot take time off from work during the day or do not have child care. Medical laboratory professionals can improve the patient experience by providing information about testing in languages other than English to support individuals for whom English is not their first language. If written patient information (e.g., ASCLS Patient Safety Tips[12]) is distributed to patients in English, it is also equitable to provide it in the predominant non-English language of individuals in the community. Equitable testing services are combined with effective testing services when reference intervals are available for parameters that have a sex-based difference (e.g., red blood cell count and hemoglobin level for individuals who are transgender) (Chapter 43). Both laboratory and hospital information systems should allow inclusion of gender identity for patients, not just listing the sex assigned at birth.

ESSENTIAL COMPETENCIES FOR HEALTH CARE PROFESSIONALS

Health Professions Education: A Bridge to Quality, published in 2003 by the Institute of Medicine, provides a blueprint to achieve quality health care.[13] It identifies the need to prepare future health care professionals with competencies to ensure health care quality. This report identifies *five competencies* considered essential for all health care professionals[13]: practice in interprofessional teams, employ evidence-based practice, provide patient-centered care, use information technology, and apply quality improvement processes. The following sections discuss why these competencies are important for medical laboratory professionals.

Interprofessional Teamwork

Students in different health care professional programs generally learn in separate programs; however, in practice, health care works best when professionals from different disciplines work as a team.[13] Communication with others is crucial, including providers who need information about test selection, nurses

who are preparing patients for testing, and clerical assistants who are entering test orders. It is important to apply expertise in all aspects of care, and for medical laboratory professionals, that often means where laboratory operations interface with nonlaboratorians who order, facilitate, or interpret laboratory tests. Working in interprofessional teams is rooted in the understanding of and respect for the scopes of practice and importance of other health care professionals. Teamwork requires a willingness to share information, to avoid and to resolve conflicts, and to approach situations with an openness to other viewpoints and priorities.[13]

Evidence-Based Practice and Patient-Centered Care

The competencies of evidence-based practice and patient-centered care create a framework on which interprofessional cooperation can be built. First, it is critical to remember that the patient should be at the center of every practice decision. If health care workers focus on the patient and their well-being, different viewpoints become an asset rather than grounds for disagreement. Additionally, when it is agreed that high-quality evidence (such as practice guidelines and peer-reviewed publications) is the basis for practice, each professional can contribute the best evidence from their own scope of practice to create a well-designed approach to patient care. Providing the best evidence to patients in a format they can understand increases shared decision making, which leads to better patient outcomes.[14]

Informatics and Quality Improvement Processes

The remaining two competencies are learned skills with significant overlap, which allow professionals to assess and improve systems. Information technology, in addition to facilitating care directly via test ordering and reporting of test results, allows health care professionals to access information and to evaluate data, for example, to locate high-quality evidence and to monitor the state of operations in their own facility.

Health care must be a continuous learning environment: as new evidence becomes available, as practice guidelines are introduced and updated, as benchmarks and outcomes are evaluated, health care professionals should strive to improve systems and processes to achieve high-quality health care. Quality improvement processes such as the Plan-Do-Study-Act (PDSA) method help to structure and monitor interventions for improvement.[15]

APPLICATIONS IN THE HEMATOLOGY AND HEMOSTASIS LABORATORY

Interprofessional Teamwork in the Hematology and Hemostasis Laboratory

Teamwork is a skill that is applicable to both the preanalytical and the postanalytical phases of testing. Uncertainty and questions often arise with test selection and specimen collection (preanalytical phase) and then again with test interpretation (postanalytical phase). Decisions on appropriate molecular testing to diagnose leukemias requires teamwork among many health care professionals in various departments such as hematology, flow cytometry, and cytogenetics (Chapters 28–34). In addition to responding to questions about tests, specimens, and results, medical laboratory professionals should be proactive with educational offerings for other health care professionals on topics that have generated repeated questions from those outside the laboratory. Providers might appreciate information about the effect of pretest probability on test interpretation (Chapter 3), for example, or the application of new parameters reported by the hematology analyzer (Chapter 13). It is important for medical laboratory professionals to maintain an attitude of availability for consultation, recognizing that neither providers nor nurses receive extensive education in these topics.[3]

Medical laboratory professionals should also be respectful of the expertise available to them from other health care professionals. Nurses may be able to provide insight about a patient's condition that impacts specimen collection, or perhaps providers can consult about unusual results or emerging diseases that relate to hematology testing.

Laboratory expertise that is shared only with other medical laboratory professionals does not always improve patient outcomes. Interpretation of complex laboratory testing may benefit from regularly scheduled, combined efforts from providers and medical laboratory professionals. In some hospitals, diagnostic management teams comprising care providers and medical laboratory professionals (pathologists, laboratory managers, and medical laboratory scientists, including those with a doctorate in clinical laboratory science [DCLS]) work together to evaluate test results from specific patients and provide patient-specific interpretive reports.[16]

Evidence-Based Practice in the Hematology and Hemostasis Laboratory

Because it can be difficult to keep up with the pace of new publications in medicine, many professional groups have joined forces to provide widely disseminated guidelines through the *Choosing Wisely* campaign.[7,8] These recommendations offer a starting point to introduce evidence-based practice into laboratory operations. For example, the *Choosing Wisely* list of the Society of Hospital Medicine-Adult Hospital Medicine (SHM-AHM) includes no repetitive CBC or chemistry testing for patients who are clinically stable (see Table 2.2). A laboratory manager could monitor tests ordered to determine if some providers regularly order repeat testing without obvious evidence of need; if so, an educational initiative may help to reduce unnecessary daily CBC orders. Alternatively, recently reported test results can be displayed within the electronic test ordering system to alert the ordering provider. Appropriate laboratory test utilization can save resources (efficiency) and improve diagnosis (effectiveness), and benefits the patient in terms of fewer specimen collections. A significant percentage of patients in intensive care units and neonatal intensive care units develop anemia during hospitalization, with phlebotomy performed for numerous specimen collections a contributing factor.[17,18] In addition, the *Choosing Wisely* statements are short and simple enough to provide patient-friendly information, allowing patients to engage in their own care planning through conversations with providers.

Patient-Centered Care in the Hematology and Hemostasis Laboratory

The importance of patient-centered care is emphasized by its inclusion in both the six health care quality aims and the five essential competencies described earlier in "Six Aims of Health Care Quality" and "Essential Competencies for Health Care Professionals," respectively. The NAM endorses a model of patient-centered care that specifies care and communication that respect patient values and preferences, coordinated care with well-managed transitions, provision of adequate information and education, attention to physical comfort, emotional support, and involvement of family and friends of the patient.[14]

Coordinated care includes interprofessional communication, establishment of responsibility and accountability, and anticipating and meeting patients' needs.[19] Proactively providing information about community transportation options for patients who need to schedule additional laboratory procedures can increase compliance with their treatment plan. Creating a procedure to establish which office will transmit results from emergency department visits to primary care providers will help to ensure continuity of care. Communication with patients by medical laboratory professionals can improve patient compliance with recommended medication-related testing.[20] Medical laboratory professionals generally have limited patient interaction and therefore little communication with the patient directly, but attention to communication among professionals can improve care coordination. For example, coordinating results between a hematology laboratory and cytology department regarding body fluid specimens (Chapter E4) increased the detection of malignancies and helped to define the educational interventions required to maintain the improvement.[21]

Medical laboratory professionals can directly affect patient care by helping patients (and those close to them) understand their laboratory test results. Patient portals provide increased access to results, but this is unlikely to help patients engage in their care if the information is not meaningful for nonmedical professionals. In a study piloting a user-centered design for laboratory test results, Zhang and colleagues[22] determined that patients found many laboratory reports difficult to read and interpret, with desired information missing or not understandable (such as the implications of abnormal results and next steps). Additionally, providers may find it difficult to extract useful information from reports of complex testing, such as molecular diagnostics.[23] A good starting point would be to track questions received in the laboratory and provide education about the most common inquiries. Providing reports that meet users' needs will require a joint effort between medical laboratory professionals and providers or patients because only the end users (that is, patients or providers) can determine if the information is usable for them.[24]

Informatics in the Hematology and Hemostasis Laboratory

The value of informatics in the laboratory, as in other applications of big data, lies in the ability to draw conclusions from large quantities of available data. The process of data analytics may not be required for laboratory practice, but understanding the potential questions to ask and application of the answers are essential. Data analyses provide a base on which to build each of the other competencies. In a particular facility, questions could include the following:

- What testing patterns indicate a need for clinical decision support systems (e.g., diagnostic algorithms or test bundles)?
- What is the current best evidence for interpretation of a particular analytical procedure?
- How can patients and families access the information they need to participate in shared decision making about their care plan?
- Does the outcome of a particular system meet criteria from benchmark institutions?

Informatics can also move the overall function of the laboratory forward in a more holistic manner. For example, extensive harmonization of laboratory testing and reporting can ensure that patient results for the same analyte from different laboratories are directly comparable.[25] Future models suggest a more extensive integration of disciplines, such as radiology and pathology, to improve diagnosis and therapeutic decisions.[26] Each of these advances requires laboratory data to be widely available and consistently mined for information.

Quality Improvement in the Hematology and Hemostasis Laboratory

Quality improvement, also known as process improvement, involves monitoring the results of a system or process to determine if the system is functioning optimally. If data show that the results could be improved, a structured plan is developed to sequentially apply changes to the system (interventions), with continued monitoring to identify changes that may result.[27] Systems thinking and quality improvement concepts initially proved useful in other industries, such as aviation and manufacturing, and their incorporation into health care has resulted in significant improvement for many patient safety indicators.[28]

In the hematology and hemostasis laboratory, potential quality improvement projects span all phases of the Total Testing Process. Preanalytical outcomes might include the rate of specimen rejection due to defects in specimen quality (e.g., clots or inadequate blood volume in sodium citrate tubes). Analytical indicators could include failures to recognize an interfering substance (e.g., lipemia causing an erroneously high hemoglobin value). Projects evaluating the postanalytical phase could monitor stat turnaround times or rate of failure to report critical values correctly.[27]

How Can Medical Laboratory Professionals Achieve Competency in These Areas?

Each of the essential competencies requires intentional preparation and specific learning methods. Few people will enter the medical laboratory profession with an intuitive understanding of quality improvement processes, and simply participating in group projects does not necessarily develop teamwork skills. The education of medical laboratory professionals is always challenging, with an ever-growing body of knowledge and limited time or opportunity for interprofessional activities. New professionals may need to investigate individual opportunities to acquire one or more of these skills, but the effort will pay off in improved patient outcomes.[29]

SUMMARY

- Patient safety encompasses all aspects of each patient's experience with the health care system.
- It is the responsibility of every health care professional to ensure that patients receive care that is safe, effective, timely, efficient, patient centered, and equitable.
- Improving medical laboratory testing requires that medical laboratory professionals develop skills in each of the five patient safety competencies: practicing in interprofessional teams, employing evidence-based practice, using information technology, applying quality improvement processes, and providing patient-centered care.

Now that you have completed this chapter, go back and read again the case study at the beginning and respond to the questions presented. Answers can be found in Appendix C.

REVIEW QUESTIONS

Answers can be found in Appendix C.

1. Which one of the following is an example of improving patient safety for patients who require a laboratory test as part of their health care?
   - **a.** Counting the number of clotted specimens for a CBC received by the laboratory
   - **b.** Measuring the amount of time it takes for a CBC to be reported to the provider
   - **c.** Ensuring that the correct laboratory test is performed for the patient's condition
   - **d.** Wearing a laboratory coat and gloves while analyzing specimens
2. What is the focus of the National Academy of Medicine's definition of health care quality?
   - **a.** Meeting College of American Pathologists accreditation requirements
   - **b.** Improving patients' health outcomes
   - **c.** Meeting The Joint Commission accreditation requirements
   - **d.** Improving laboratory proficiency testing outcomes
3. Which one of the following examples of collected data is needed for a medical laboratory professional to improve the efficiency of the preanalytical phase of the Total Testing Process in the clinical laboratory?
   - **a.** The number of underfilled sodium citrate tubes for prothrombin time procedures
   - **b.** The number of times the quality control specimens are outside ± 2 SD
   - **c.** The number of times the proficiency testing does not meet requirements
   - **d.** The number of times a prothrombin time procedure needs to be repeated
4. Which one of the following actions can lead to harm for a patient who needs laboratory testing?
   - **a.** Asking the patient their name and birth date before performing venipuncture for a CBC
   - **b.** Reviewing the results of the quality control specimens before analyzing the patient's specimen
   - **c.** Sending an abnormally low platelet count result to a provider without completing the required confirmation checks
   - **d.** Daily maintenance on the coagulation analyzer before analyzing quality control specimens
5. Which one of the following is an example of improving the effectiveness of hematology laboratory testing?
   - **a.** Following the guidelines promoted by *Choosing Wisely* for inpatients
   - **b.** Counting the number of clotted CBC specimens received in the laboratory
   - **c.** Measuring the amount of time it takes for a CBC to be completed after it is collected
   - **d.** Performing quality control on the hematology analyzer before analyzing patient specimens
6. Which one of the following statements accurately characterizes the subject of *Crossing the Quality Chasm*?
   - **a.** Certain competencies are essential for all health care professionals.
   - **b.** Good health care can be described using six different dimensions of care.
   - **c.** Laboratory records should include quality control and proficiency testing results.
   - **d.** Many Americans experience harm as a result of health care procedures.
7. Which one of the following is an example of interprofessional teamwork?
   - **a.** An interpreter was hired by the laboratory director to translate patient venipuncture preparation instructions into Vietnamese to accommodate a large immigrant population.
   - **b.** Medical laboratory scientists in the hematology laboratory discuss an unusual abnormal cell found on a slide.
   - **c.** The charge nurse on one floor asks the medical laboratory scientist in hematology to create an educational presentation about anticoagulants and phlebotomy.
   - **d.** The *Choosing Wisely* campaign recommends a C-reactive protein level to detect inflammation instead of the erythrocyte sedimentation rate.
8. Which one of the following illustrates evidence-based practice?
   - **a.** Good health care can be described using six different dimensions of care.
   - **b.** Many Americans experience harm as a result of health care procedures.
   - **c.** Medical laboratory scientists in the hematology laboratory discuss an unusual abnormal cell found on a slide.
   - **d.** The *Choosing Wisely* campaign recommends a C-reactive protein level to detect inflammation instead of the erythrocyte sedimentation rate.

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