



Hematological Anatomy, Physiology and Assessment

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Purpose & Objectives

The focus of this hematological anatomy, physiology, and assessment course is to provide information about the structures and functions of the hematopoietic system and its associated assessment. Understanding the fundamental structures and functions of the hematologic system will allow the healthcare professional to intervene effectively when a patient experiences a hematological disorder.

After successful completion of this course, the participant should be able to:

1. Discuss the functions of the hematopoietic system
2. Describe the physiology of hematopoiesis and components of the hematopoietic system
3. Discuss how to assess the oxygen carrying capacity of blood
4. Determine how to assess the immunity status of patients
5. Identify how to assess the blood's clotting ability

****Please note that laboratory values given in this course are reference ranges for adult patients only.**

Glossary

Anemia: A deficiency of red blood cells or of hemoglobin in the blood, resulting in pallor and weariness.

Clotting cascade: A sequence of events culminating in the formation of a blood clot.

Erythrocytes: Red blood cells

Erythropoietin: A hormone that stimulates the production of red blood cells by stem cells in bone marrow.

Ferritin: A protein that binds to iron.

Granular leukocytes: (Also known as granulocytes), are leukocytes that have the presence of granules in their cytoplasm.

Hematocrit: A measure of the total percentage of blood volume that is composed of red blood cells.

Hematology: The science of blood and blood forming tissues.

Hematopoiesis: The continuous, regulated formation of blood cells.

Hematopoietic system: Consists of organs and tissues, primarily the bone marrow, spleen, tonsils, and lymph nodes, involved in the production of blood.

Hemoglobin: A protein-iron compound in red blood cells that carries oxygen from the lungs to the rest of the body.

Hypoxemia: An abnormally low concentration of oxygen in the blood.

Hypoxia: Refers to low oxygen-carrying capacity of the blood.

Leukocytes: White blood cells.

White blood cells: Leukocytes that lack granules in their cytoplasm.

(Mosby, 2016; Venes, 2017)

Introduction

The anatomy, physiology, and functions of the hematopoietic system are all involved in the production of blood.

Hematologic activities, such as red blood cell formation and the clotting cascade, require a complex series of events to allow good health and homeostasis.

Without leukocytes to protect us, our bodies could succumb to disease and infection.

As a healthcare professional, a basic understanding of hematological functions is important in providing appropriate patient care.

Hematopoietic System

Hematology is the science of blood and blood forming tissues. It includes both cellular and non-cellular blood components. The hematopoietic system consists of organs and tissues, primarily the bone marrow, spleen, tonsils, and lymph nodes, involved in the production of blood (Mosby Company, 2016).

Blood is composed of two elements:

- A liquid component known as plasma
- The solid components, which are mainly erythrocytes, leukocytes, and thrombocytes

The solid components of blood are formed by hematopoiesis, which is the continuous, regulated formation of blood cells.

There are three primary functions of hematopoiesis:

1. Oxygen delivery
2. Hemostasis
3. Host defense

Hematological activities occur in many organs of the body and have the potential for multiple forms of pathology (Rodgers & Young, 2018).

Hematopoiesis

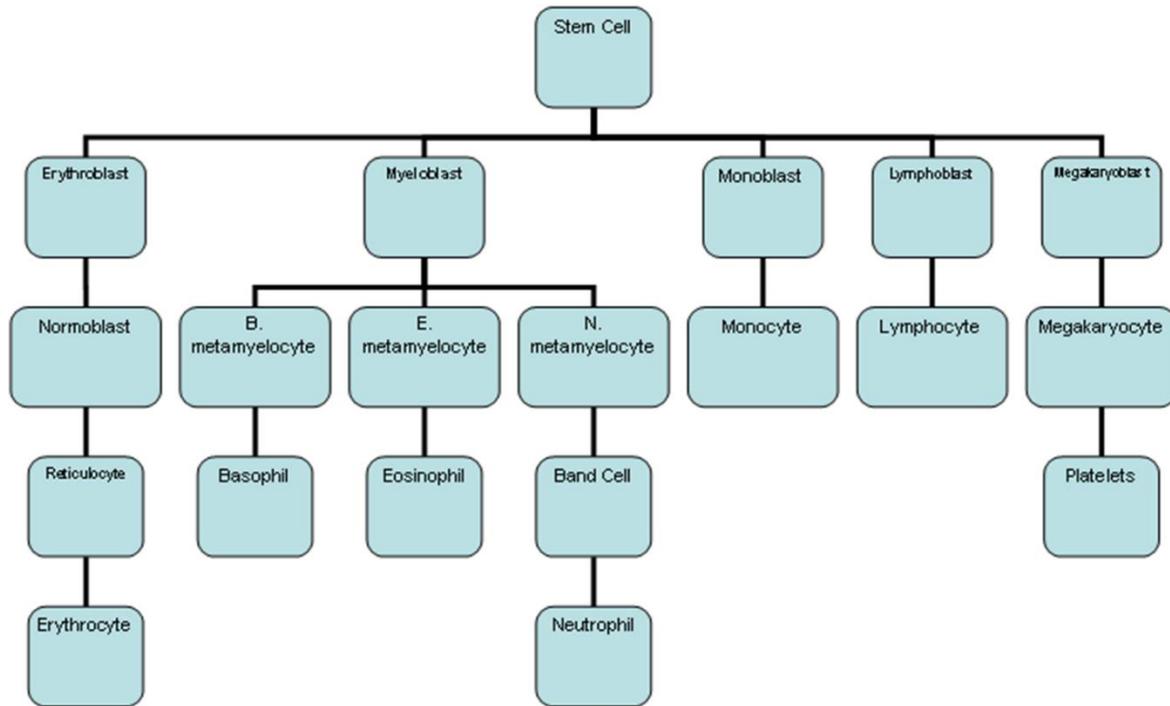
Hematopoiesis, the formation of blood cells, occurs in the bone marrow. The degree and location of bone marrow activity varies depending on the age and health status of the patient.

Within the bone marrow, there is a pluripotent stem cell. This stem cell is the “Mother Cell” or the originator of all blood cells. It has the ability to self-renew and create progenitor stem cell lines. They are naturally limited in number (Keohane, Smith, & Walenga, 2015).

By reviewing the chart on the next screen, you can see that all cells come from the stem cell. An attack on the stem cell can theoretically affect all cells similarly.

A disease or agent that impacts erythroblasts could impact all the cell type in that “line,” but not those in a different “line.”

Stem Cell Chart



Test Yourself

Which of the following statements is true of hematopoiesis?

- A. The process occurs in the spleen
- B. It is the formation of plasma
- C. It is the formation of blood cells

The correct answer is C.

Erythrocytes

Erythrocytes, or red blood cells (RBCs), originate from a stem cell.

Vitamin B12, folic acid, iron, and copper are essential in the formation of erythrocytes.

Erythropoietin is a hormone released by the kidneys in response to hypoxemia, which stimulates the bone marrow to produce red blood cells.

Typically, red blood cells live approximately 120 days. When the red blood cells become old and damaged, the liver, spleen, and bone marrow cleanse them from the blood.

Increases or decreases in the red blood cell count indicate an abnormality.

Please note that laboratory values given in this course are reference ranges only (Rush Medical University Center, 2015), as values vary at different laboratories.

Normal RBC Range:

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Males: 4.5 – 5.9 mil/uL

Females: 4.0 - 5.2 mil/uL

Reticulocytes

When released from the bone marrow, red blood cells are slightly immature and are known as reticulocytes.

Reticulocytes mature into red blood cells within a few days.

The number of reticulocytes in the blood indicates the amount of bone marrow activity.

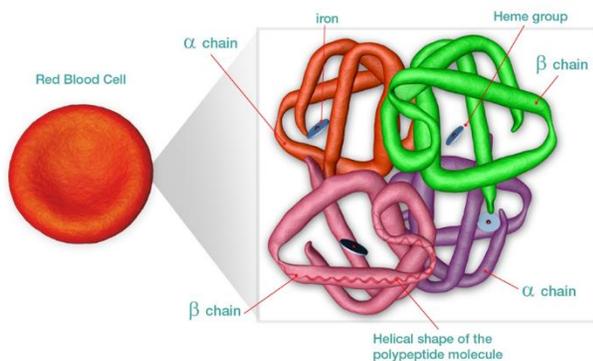
Low reticulocyte counts may be due to vitamin deficiency, liver cirrhosis, or radiation therapy (Keohane, Smith, & Walenga, 2015).

Normal Reticulocyte Range:

0.5-2.5% of RBCs

Hemoglobin

Hemoglobin is a protein-iron compound in red blood cells that carries oxygen from the lungs to the rest of the body.



Hemoglobin is a laboratory value used to evaluate the oxygen-carrying capacity of the blood.

Low levels of hemoglobin in the blood represent anemia (Rodgers & Young, 2018).

One unit of packed red blood cells generally equals one whole number increase in the hemoglobin value.

For example:

If a patient's hemoglobin is 7.0 g/dL, and one unit of packed red blood cells is administered, the patient's hemoglobin should come up to 8.0 g/dL.

Normal Hemoglobin Range:

Males: 13.5 – 17.5 g/dL

Females: 12.0 – 16.0 g/dL

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Test Yourself

Administering two units of packed red cells should increase the patient's hemoglobin by two whole numbers.

- A. True
- B. False

The correct answer is A.

Hematocrit

Hematocrit is a measure of the total percentage of blood volume that is composed of red blood cells.

It is also known as the packed cell volume (PCV).

Low levels of hematocrit may indicate:

- Anemia
- Blood loss
- A disease process such as cancer

High levels of hematocrit may be due to:

- Dehydration
- Blood disorders

(Rodgers & Young, 2018)

Normal Hematocrit Range:

Males: 42-54%

Females: 37-47%

Mean Corpuscular Volume

The mean corpuscular volume (MCV) is the average volume of red cells in a specimen. MCV is elevated or decreased in relation to the average red cell size. Low MCV indicates small average RBC size, normal MCV indicates normal average RBC size, and high MCV indicates large average RBC size (Curry, 2015).

Normal MCV Range:

82 - 103 fL

Mean Corpuscular Hemoglobin

The mean corpuscular hemoglobin, or MCH, is the content or weight of hemoglobin of the average red cell. MCH demonstrates the hemoglobin mass in red cells (Merritt, 2014).

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Normal MCH Range:

26 - 34 pg

Erythrocyte Sedimentation Rate

The erythrocyte sedimentation rate (ESR) is the rate at which red blood cells settle out when anticoagulated whole blood is allowed to stand. The ESR is affected by the concentrations of immunoglobulins and acute phase proteins. The ESR is a sensitive, but nonspecific, indicator of inflammation and tissue damage (Kellner, 2014).

Normal ESR Range:

Males: 0 - 17 mm/hour (may be slightly higher for age >50)

Females: 0 - 27 mm/hour (may be slightly higher for age > 50)

Test Yourself

Anemia can be represented by:

- A. Low hemoglobin
- B. Low hematocrit
- C. Both

The correct answer is C.

Iron

Iron is necessary for the formation of hemoglobin, an essential part of the red blood cell.

Iron is absorbed from the small intestine into the blood and binds with a protein called transferrin.

Transferrin transports iron to the bone marrow, where it is used to make hemoglobin.

Lower than normal iron levels may be related to:

- Inadequate iron intake
- Inadequate iron absorption
- Chronic blood loss

High levels of iron can be due to:

- Blood disorders
- Hepatitis B
- Vitamin deficiency
- Iron poisoning

(Rodgers & Young, 2018)

Normal Iron Range:

35 - 170 mcg/dL

Total Iron Binding Capacity

The amount of iron that can still bind with transferrin (to be transported to bone marrow to make hemoglobin) is known as the total iron binding capacity or TIBC.

Think of TIBC as the total amount of people that can get on a bus. The iron is the people and the bus is transferrin.

When the serum iron levels increase, the TIBC level will decrease, as the ability to bind the high levels of circulating iron is impaired.

When serum iron levels decrease, TIBC increases, as the ability to bind circulating iron is increased (Rodgers & Young, 2018).

Normal Total Iron Binding Capacity:

196 - 364 /dL

Ferritin

Ferritin is a protein that binds to iron. Most of the iron stored in the body is attached to ferritin.

Ferritin is found in the liver, spleen, and bone marrow. Only a small amount is found in the blood.

Like the TIBC, the amount of ferritin in the blood may help indicate the amount of iron stored in the body (Rodgers & Young, 2018).

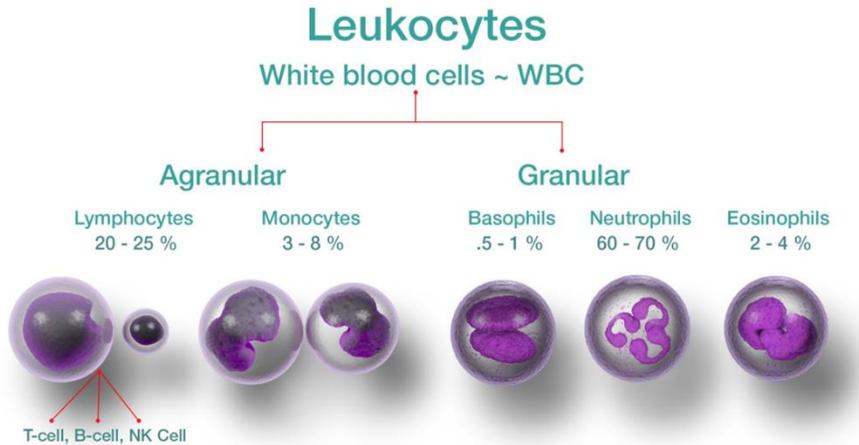
Normal Ferritin Range:

Males: 12 - 410 ng/mL

Females: 12 - 260 ng/mL

Leukocytes

Leukocytes, or white blood cells, help to protect the body from bacteria and infection.



Leukocytes

Leukocytes are typically classified as either:

- Granular leukocytes: Includes neutrophils, eosinophils and basophils
- Non-granular leukocytes: Includes lymphocytes, monocytes, and plasma cells

In a healthy individual, the total white blood cell (WBC) count increases in response to infection or trauma.

Individuals that are immunosuppressed often have a low WBC count and are much more susceptible to infection.

The WBC count is expressed as the number of leukocytes per micro liter of blood.

Normal Leukocyte Range:

4,000 -10,000 / uL

Granular Leukocytes

Neutrophils

Neutrophils are granular leukocytes that function to kill bacteria. Neutrophils act by destroying the ability of bacteria to reproduce, and they destroy bacteria's ability to produce endotoxins.

Neutrophils also release enzymes and substances that affect other cells functions.

An increased number of neutrophils may indicate an acute infection (Keohane, Smith, & Walenga, 2015).

Neutrophil Bands

Neutrophil's primal cell type is bands. Bands are adolescent neutrophils, and it is abnormal to have elevated bands in the blood stream. Neutrophils increase in number when an acute bacterial infection is present.

Historically, lab reports were hand-written, and elevated neutrophil bands were recorded on the left. Today, the presence of elevated neutrophil bands indicates the presence of an inflammatory process and the term "shift to the left" means that the bands have increased, indicating an infection in progress (Keohane, Smith, & Walenga, 2015).

Did You Know?

The term "shift to the left" or "left shift" began with manual differentials of white blood cells. The mature neutrophils were noted on the right, and were more immature as they progressed to the left. In an infection, the body sends out the mature cells first, followed by the immature cells. When there are more immature cells (i.e. bands) noted than mature cells, this is noted as a "shift to the left."

Eosinophils

Eosinophils are responsible for fighting parasites, and are increased in allergic or autoimmune disorders. For example, eosinophils increase when a patient has hives due to allergic reaction.

Basophils

Basophils make up a small portion of the white blood cell count. Basophils release histamine, heparin, and have a role in the body's immune response (Keohane, Smith, & Walenga, 2015).

Test Yourself

Neutrophils main responsibility is to kill bacteria by destroying the bacteria's ability to produce ____.

- A. Bands
- B. Ferritin
- C. Leukocytes
- D. Endotoxins

The correct answer is D.

Non-Granular Leukocytes

Lymphocytes

Lymphocytes mature in the lymph nodes. They live approximately 100-300 days.

The total lymphocyte count represents total T and B lymphocytes. T lymphocytes are killer cells, and instruct B lymphocytes to produce antibodies.

Lymphocytes increase in viral illnesses, such as measles, mumps, chicken pox, influenza, viral hepatitis, mononucleosis, and in acute transplant rejection.

Monocytes

Monocytes are phagocytic cells. They ingest cellular debris at the area of infection or inflammation.

They increase after several days of active infection or inflammation. Activated monocytes recognize a number of micro-organisms and will engulf and destroy them.

Plasma

Plasma is a straw-colored, clear liquid that is ninety percent water. It is essential for the transport of blood components.

In addition to water, plasma also contains dissolved electrolytes responsible for membrane excitability, and plasma proteins that maintain the osmotic distribution of fluid and substances capable of buffering pH changes (Keohane, Smith, & Walenga, 2015).

Blood Clotting: Platelets

Platelets are small, colorless cells that have a lifespan of seven to ten days.

Blood Clotting: Platelets

Platelets perform three major roles:

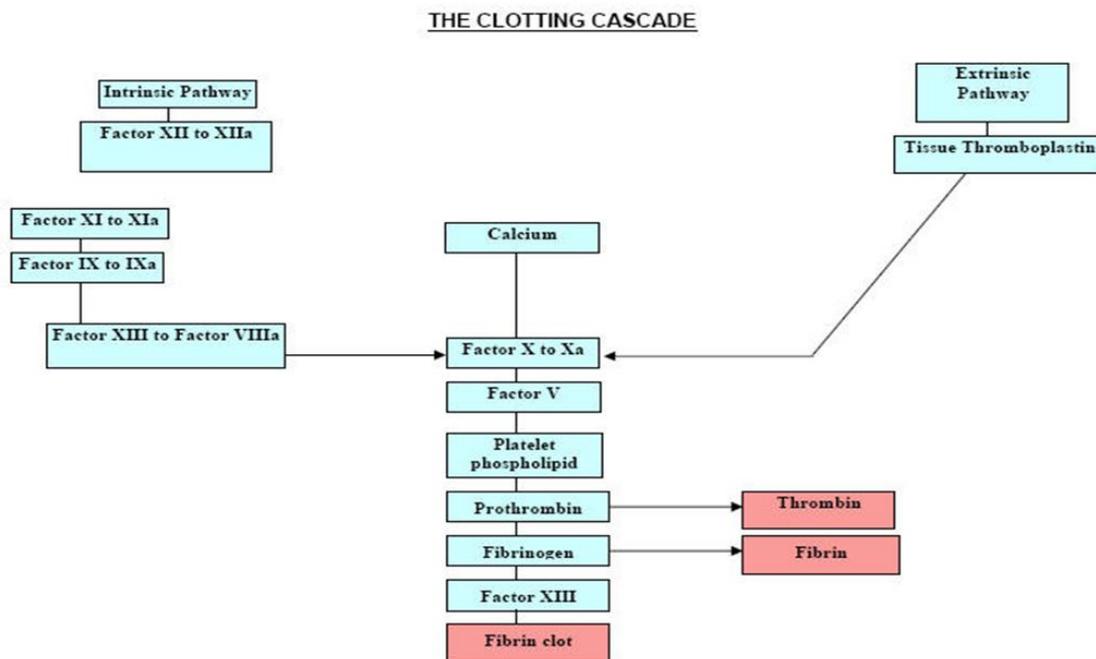
- A. Decreasing the luminal size of damaged vessels to decrease blood loss.
- B. Forming blockages in injured vessels to decrease blood loss.
- C. Providing support accelerate blood coagulation through molecules on the surface of the platelets.

To truly understand the clotting mechanism of the body, review the clotting cascade table on the next page.

Normal Platelet Range:

150,000 - 399,000 / x10³ /mm³

The Clotting Cascade



The Clotting Cascade

The end result of the clotting cascade is:

- Fibrin clots
- Fibrin
- Thrombin

When the clotting cascade is activated, usually due to vessel injury or damage, platelets are one of the first responders. They stick to the damaged vessel and recruit more platelets to the site. This aggregation of platelets forms a temporary plug that safeguards the vessel wall from further bleeding.

Simultaneously, additional proteins from the clotting cascade are activated in a specific order that lead to the formation of fibrin.

Fibrin is a very sticky substance and acts as glue at the site, securing the platelet plug.

Finally, the clot must be dissolved in order for normal blood flow to resume following tissue repair.

The dissolution of the clot occurs through the action of plasmin, which is a protein responsible for digesting fibrin. Eventually, scar tissue forms completing the healing of the injured vessel (Keohane, Smith, & Walenga, 2015).

Assessment of Clotting

Assessment of clotting requires the nurse to examine the patient's history, physical exam findings, and review of clotting studies.

When obtaining a patient history, ask about:

- The frequency and ease of bruising
- The presence of bleeding gums, or heavy menstrual periods
- The presence of blood in vomitus, stools, or urine
- The presence of petechiae

When assessing your patients clotting ability, look for signs and symptoms of bleeding such as:

- Bruising
- Low blood pressure with an increased pulse rate (internal bleeding)
- Firm, tender abdomen
- Positive occult blood in stool or gastric contents

Examine the complete blood count and serum clotting factors lab results (Jarvis, 2015).

Review of Clotting Factors

Blood Component	Normal Value	Elevated when...(↑)	Decreased when...(↓)
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Platelets	150,000-399,000 / $\times 10^3$ /mm ³	<ul style="list-style-type: none"> * Thrombocytopenia * Sleep dysfunction * Dehydration 	<ul style="list-style-type: none"> * Leukemia * Platelet antibody presence * AIDs * Bone marrow suppression
PT (Prothrombin Time)	9.5-13.2 seconds	<ul style="list-style-type: none"> * Vitamin K deficiency * Liver disease * Disseminated intravascular coagulation (DIC) * Aspirin overdose * Anticoagulant therapy 	<ul style="list-style-type: none"> * Enteritis
INR	2.0-3.0 for embolism 2.5-3.5 for mechanical heart valves	<ul style="list-style-type: none"> * Same as PT 	<ul style="list-style-type: none"> * Same as PT
aPTT (activated partial thromboplastin time)	23-33 seconds	<ul style="list-style-type: none"> * Liver disease * DIC * Heparin therapy 	<ul style="list-style-type: none"> * Acute hemorrhage * Extensive cancer
Fibrinogen	190-395 mg/dL	<ul style="list-style-type: none"> * Rheumatoid arthritis * Hepatitis * Acute infection 	<ul style="list-style-type: none"> * Liver disease * DIC * Recent trauma

Assessment of the Hematological System

When assessing your patient's hematological system, it is important to ask questions that reveal clues about the oxygen carrying capacity of their blood.

Obtaining a thorough health history will assist you to identify any risk factors that could influence your patient's hematological status.

Assessment of the oxygen-carrying capacity of the blood requires the nurse to review the patient's history, physical exam findings, and the lab results of their complete blood count with differential.

History & Physical Clues

Ask your patient about the ease in which they perform activities of daily living, to determine if hypoxia is present.

Inquire about fatigue, shortness of breath, or episodes of breathlessness. These assessment findings may clue you in to a potential hematological deficiency.

Common blood-related causes of hypoxia (low oxygen-carrying capacity of the blood) include:

- Low number of circulating red blood cells
- Poor supply of hemoglobin within these red blood cells

- Carbon monoxide poisoning

Physical clues that will aid in assessing oxygen-carrying capacity include:

- Skin coloration
- Respiratory rate
- Pattern of respiration
- Capillary refill
- Heart rate
- Skin temperature

(Jarvis, 2015)

Test Yourself

A physical clue that can be used for assessing hypoxia is:

- A. Blood pressure
- B. Respiratory rate
- C. Oral temperature

The correct answer is B.

Analysis of Blood Components

A complete blood count is often used to augment the history and physical examination. Normal values and conditions associated with altered oxygen-carrying capacity of the blood within the complete blood count with differential are summarized in the tables on the next two pages.

Blood Component	Normal Value	Elevated when...(↑)	Decreased when...(↓)
Red Blood Cell (RBC)	4.5-5.9 /mil/uL (males) 4.0-5.2 mil/uL (females)	* Chronic pulmonary disease * Cardiovascular disease * High altitude	* Chronic renal failure * Bone marrow damage * V B12 or folic acid deficiency * Hemolysis * Hemorrhage * Anemia of chronic disease (systemic lupus, Rheumatoid arthritis, infection, bacterial endocarditis, AIDs, Crohn's disease, some malignancies)

Reticulocyte Count	0.5-2.5% of RBCs	<ul style="list-style-type: none"> * Anemia * Hemorrhage * Hemolysis * Leukemia * Pregnancy 	<ul style="list-style-type: none"> * Bone marrow failure * Radiation therapy * Chronic infection * Liver cirrhosis * Folic acid deficiency
Hemoglobin	13.5-17.5 g/dL (males) 12.0-16.0 g/dL (females)	<ul style="list-style-type: none"> * Polycythemia * Dehydration 	<ul style="list-style-type: none"> * Anemia * Hypervolemia * Bleeding problems * Bone marrow suppression
Hematocrit	42-54% (males) 37-47% (females)	<ul style="list-style-type: none"> * Polycythemia * Dehydration 	<ul style="list-style-type: none"> * Anemia * Hypervolemia * Bleeding problems * Bone marrow suppression

Blood Component	Normal Value	Elevated when...(↑)	Decreased when...(↓)
Iron	35-170 mcg/dL	<ul style="list-style-type: none"> * Hemolysis * Hemolytic anemias 	<ul style="list-style-type: none"> * Dietary deficiency * Excessive blood loss * Iron deficiency anemia
Total Iron Binding Capacity (TIBC)	196-364 mcg/dL	<ul style="list-style-type: none"> * Iron deficiency anemia * Acute or chronic blood loss * Polycythemia * Pregnancy 	<ul style="list-style-type: none"> * Hemolytic anemias * GI cancers * Liver cirrhosis
MCV (Mean Corpuscular Volume)	82-103 fL	<ul style="list-style-type: none"> * Pernicious anemia * Folate deficiency * Chronic liver disease 	<ul style="list-style-type: none"> * Iron deficiency anemia * Thalassemia * Rheumatoid arthritis * Lead poisoning * Malignancy

MCH (Mean Corpuscular Hemoglobin)	26-34 pg	<ul style="list-style-type: none"> * Pernicious anemia * Folic acid deficiency anemia 	<ul style="list-style-type: none"> * Iron deficiency anemia * Thalassemia
ESR (Erythrocyte Sedimentation Rate)	0-17 mm/hour (males) 0-27 mm/hour (females) (may be slightly higher for age >50)	<ul style="list-style-type: none"> * Inflammation 	<ul style="list-style-type: none"> * None

Reviewing WBC Count with Differential

Blood Component	Normal Value	Elevated when...(↑)	Decreased when...(↓)
White Blood Cell	4,000-10,000 /uL	<ul style="list-style-type: none"> * Infection * Trauma * Post op day #1 * Leukemias 	<ul style="list-style-type: none"> * Immune disorders * HIV * Cancer * Chemotherapy * Bone marrow suppression
Neutrophils	46-78%	<ul style="list-style-type: none"> * Bacterial infection 	<ul style="list-style-type: none"> * Bone marrow suppression * Severe infection/sepsis
Bands	0-6%	<ul style="list-style-type: none"> * Acute bacterial infection 	<ul style="list-style-type: none"> * Severe infection/sepsis
Lymphocytes	18-52%	<ul style="list-style-type: none"> * Viral illness * Rejection of transplant tissue 	<ul style="list-style-type: none"> * Bone marrow suppression
Monocytes	3-10%	<ul style="list-style-type: none"> * Several days of active infection 	

Eosinophils	0-6%	<ul style="list-style-type: none"> * Allergic disorders * Parasitic infections * Autoimmune disorders 	
Basophils	0-3%	<ul style="list-style-type: none"> * Healing process 	

Assessment of Immunity: History

Assessment of immunity requires the nurse to examine the patient's history, physical exam findings, and the white count with differential result.

When assessing your patient's immunity status be sure to ask about the following:

- Recurrent infections
- Chronic conjunctivitis
- Chronic diarrhea caused by Giardia
- Arthritis-like symptoms
- Autoimmune diseases
- Allergies

Recurrent infections, chronic conjunctivitis, and chronic diarrhea (caused by Giardia) indicate a possible attack on the immune system or an underactive, low functioning immune system.

Allergies, autoimmune disease, and arthritis like symptoms are disease processes that are related to auto-immunity. When the immune system response is altered and does not recognize the body's cells as being part of the host, these symptoms may occur.

Test Yourself

A disease process related to auto immunity is:

- A. Recurrent infections
- B. Allergies
- C. Chronic diarrhea

The correct answer is B.

Assessment of Immunity: Physical Clues

Physical clues that will aid in assessing the immunity status of your patient include:

- Inspection of open sores in the mouth
- Signs of chronic inflammation, such as body aches or pains
- Presence of wounds that are not healing in a timely manner

When assessing a patient's immunity status, the healthcare professional should examine the patient's white cell count and differential.

Conclusion

A thorough knowledge of hematological anatomy and physiology paired with appropriate assessment techniques is essential in effectively caring for patients, especially those with blood-related disorders.

A good understanding of hematological processes will allow you to successfully care for patients with the most minor hematological problems to those experiencing hematological emergencies.

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