# IRON METABOLISM, HEMOSTASIS, AND THE CLINICAL APPLICATION OF BIOCHEMICAL ANALYSIS METHODS: DIAGNOSTIC SIGNIFICANCE OF NORMAL BLOOD AND URINE BIOCHEMICAL PARAMETERS

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**Abstract** Iron metabolism and hemostasis are essential physiological processes that maintain oxygen transport, cellular energy production, and vascular integrity. Disturbances in these systems contribute significantly to the global burden of anemia, thrombotic disorders, hemorrhagic diseases, and chronic inflammatory conditions. Modern clinical biochemistry provides numerous laboratory methods for assessing iron homeostasis and coagulation status. Biochemical evaluation of blood and urine parameters remains fundamental for early diagnosis, prognosis, and monitoring of disease progression. This review summarizes current knowledge regarding iron metabolism, regulatory mechanisms of hepcidin and ferroportin, hemostatic pathways, and the clinical application of biochemical analysis methods. Furthermore, normal reference ranges of blood and urine biochemical markers are discussed, emphasizing their practical use in clinical medicine. Recent advances in laboratory diagnostics, including ferritin, transferrin saturation, soluble transferrin receptor, and novel biomarkers, are also reviewed.

**Keywords:** Iron metabolism, hemostasis, ferritin, transferrin, hepcidin, biochemical analysis, blood biochemistry, urine biochemistry, clinical diagnostics.

## Introduction

Iron is an indispensable trace element required for oxygen transport, mitochondrial respiration, DNA synthesis, and numerous enzymatic reactions. Approximately 3–5 g of iron is present in the adult human body, with most incorporated into hemoglobin and myoglobin. [1,2,3,4,5,6,7] The maintenance of iron homeostasis is critical because both deficiency and overload can result in pathological consequences.

Hemostasis is a tightly regulated physiological process that prevents excessive blood loss while maintaining blood fluidity within vessels. It involves vascular responses, platelet activation, coagulation cascades, and fibrinolysis. Abnormal hemostasis may lead to thrombosis or hemorrhage, contributing substantially to cardiovascular morbidity and mortality.[8,9,10,11,12]

Advances in laboratory medicine have enabled precise assessment of iron metabolism and hemostatic function through biochemical markers measured in blood and urine. These analyses support evidence-based clinical decision-making and personalized patient management.[13,14,15,16]

## Physiology of Iron Metabolism

Iron metabolism consists of four major processes:

1. Intestinal absorption
2. Transport in circulation

3. Cellular utilization and storage
4. Recycling from senescent erythrocytes

Dietary iron is absorbed mainly in the duodenum. Ferric iron ($Fe^{3+}$) is reduced to ferrous iron ($Fe^{2+}$) before transport into enterocytes. Once absorbed, iron binds to transferrin for systemic distribution.

The liver serves as the principal regulator of systemic iron homeostasis through synthesis of hepcidin, a peptide hormone that controls ferroportin-mediated iron export from enterocytes and macrophages. Elevated hepcidin reduces plasma iron concentrations, whereas decreased hepcidin promotes iron absorption and release from storage sites. [17,18,19,20]

**Molecular Regulation of Iron Homeostasis**

Several proteins participate in iron regulation:

| Protein | Function |
|---|---|
| Hepcidin | Master regulator of iron metabolism |
| Ferroportin | Cellular iron exporter |
| Ferritin | Iron storage protein |
| Transferrin | Iron transport protein |
| Transferrin receptor | Cellular iron uptake |
| DMT1 | Intestinal iron absorption |

Recent studies demonstrate that the hepcidin–ferroportin axis plays a central role in iron-related disorders, including anemia of chronic disease and hereditary hemochromatosis.

**Clinical Disorders of Iron Metabolism**

**Iron Deficiency**

Iron deficiency remains the most prevalent nutritional disorder worldwide. Clinical manifestations include:

- Fatigue
- Weakness
- Cognitive impairment
- Reduced immune function
- Iron-deficiency anemia

Laboratory findings include:

- Decreased serum ferritin
- Reduced serum iron
- Increased total iron-binding capacity (TIBC)
- Reduced transferrin saturation

**Iron Overload**

Iron overload may occur due to:

- Hereditary hemochromatosis
- Repeated blood transfusions
- Chronic liver disease

Biochemical indicators include:

- Increased ferritin
- Increased transferrin saturation (>45%)
- Elevated hepatic iron stores

**Hemostasis and Coagulation Mechanisms**

Hemostasis consists of three interconnected stages:

**Primary Hemostasis**

Primary hemostasis involves:

- Vasoconstriction
- Platelet adhesion
- Platelet aggregation

Platelets interact with exposed collagen and von Willebrand factor to form the primary platelet plug.[21,22,23,24,25]

**Secondary Hemostasis**

Secondary hemostasis activates coagulation factors leading to thrombin generation and fibrin clot formation.

The coagulation cascade includes:

- Intrinsic pathway
- Extrinsic pathway
- Common pathway

**Fibrinolysis**

After vessel repair, fibrinolysis removes fibrin clots through plasmin-mediated degradation.

Disruption of these mechanisms can result in bleeding disorders or thromboembolic disease.

**Biochemical Methods Used in Clinical Practice**

Modern laboratory medicine employs various biochemical techniques for evaluating iron status and hemostasis.

**Spectrophotometric Methods**

Widely used for:

- Serum iron
- Hemoglobin
- Creatinine
- Urea

Advantages:

- Rapid
- Cost-effective
- High throughput

**Immunochemical Assays**

Used for:

- Ferritin
- Hepcidin

- D-dimer
- Coagulation proteins

Provide high sensitivity and specificity.

**Automated Hematology Analyzers**

Measure:

- Hemoglobin
- Hematocrit
- Erythrocyte indices
- Platelet count

**Molecular Diagnostic Techniques**

Include:

- PCR-based mutation analysis
- Genetic testing for hemochromatosis
- Thrombophilia screening

**Normal Blood Biochemical Parameters**

**Hematological Parameters**

| Parameter | Normal Range |
|---|---|
| Hemoglobin (Male) | 130–170 g/L |
| Hemoglobin (Female) | 120–150 g/L |
| RBC Count | 4.0–5.9 $\times 10^{12}$/L |
| Platelets | 150–400 $\times 10^{9}$/L |
| WBC Count | 4.0–10.0 $\times 10^{9}$/L |

**Iron Status Parameters**

| Parameter | Reference Range |
|---|---|
| Serum Iron | 10–30 µmol/L |
| Ferritin (Male) | 30–400 ng/mL |
| Ferritin (Female) | 15–150 ng/mL |
| Transferrin Saturation | 20–45% |
| TIBC | 45–72 µmol/L |

**Normal Urine Biochemical Parameters**

| Parameter | Normal Range |
|---|---|
| pH | 4.5–8.0 |
| Protein | Negative |
| Glucose | Negative |
| Ketones | Negative |
| Bilirubin | Negative |
| Urobilinogen | 0.1–1.0 EU/dL |
| Specific Gravity | 1.005–1.030 |

Urine biochemical analysis assists in diagnosing:

- Kidney disease
- Diabetes mellitus
- Metabolic disorders
- Urinary tract infections

**Clinical Applications of Blood and Urine Biochemistry**

Biochemical analyses contribute to:

**Diagnosis**

- Iron-deficiency anemia
- Hemochromatosis
- Coagulation disorders
- Renal diseases

**Monitoring**

- Response to iron therapy
- Anticoagulant treatment
- Chronic kidney disease progression

**Prognosis**

- Cardiovascular risk assessment
- Inflammatory disease monitoring

Laboratory biomarkers facilitate evidence-based clinical management and improve patient outcomes.[26,27,28,29,30]

**Future Perspectives**

Emerging biomarkers such as hepcidin, soluble transferrin receptor (sTfR), non-transferrin-bound iron, and advanced coagulation markers may enhance diagnostic precision. Standardization of laboratory methodologies remains essential for improving inter-laboratory comparability and clinical interpretation.[31,32,33,34,35,36]

**Conclusion**

Iron metabolism and hemostasis are fundamental physiological systems whose disturbances contribute to numerous diseases. Modern biochemical analysis methods provide accurate and reliable tools for evaluating iron status, coagulation function, and overall metabolic health. Knowledge of normal blood and urine biochemical parameters is essential for clinical diagnosis, disease monitoring, and therapeutic decision-making. Continued development of novel biomarkers and standardized analytical methods will further strengthen laboratory medicine and improve patient care.

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