Coordination Iron And Copper Compounds In Medicine

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Abstract

This article examines the role of iron and copper coordination compounds in modern medicine and pharmacology as of 2026. It substantiates the need to transition from inorganic metal salts to complex compounds with organic ligands to increase bioavailability and reduce toxicity. The mechanisms of action of modern drugs, including ferroptosis and cuproptosis , are described, as well as the use of metal complexes in the treatment of anemia, oncology, diagnostics (MRI and PET-CT), and regenerative medicine. Particular attention is paid to innovative delivery technologies, such as liposomal formulations and the use of AI in compound modeling.

Keywords: Coordination compounds, iron, copper, pharmacology, theranostics, ferroptosis, cuproptosis, bioavailability, targeted therapy.

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1. Introduction

Coordination (complex) Iron and copper compounds are important in medicine. These elements possess unique physicochemical properties, such as variable oxidation states, the ability to form stable coordination compounds, participation in redox reactions, and specific interactions with biomolecules.

Objective of the study: Iron-copper complexes are widely used in diagnostics, therapy, pharmacology, and biochemistry. Many of them are components of enzymes, drugs, and contrast agents, and are also considered promising agents for the treatment of oncological, infectious, and metabolic diseases.

2. Methods

The study is based on an analysis of modern pharmaceutical developments, computer modeling data (MetalloDock system), and clinical trials of third-generation iron and copper preparations. The mechanisms of interaction between metal ions and amino acids, proteins, and polysaccharides were examined.

3. Results And Discussion

The role of complexation in pharmacology

Iron and copper are known to be biologically essential elements for normal functioning. However, their inorganic salts have a toxic effect on the human body. Consequently, it is necessary to synthesize complex compounds of these elements with organic ligands. Amino acids, proteins, nucleic acids, amino acids, vitamins, and medicinal substances are used as organic ligands. Binding organic ligands to iron and copper ions radically alters their properties:

- Increased bioavailability: Complexation improves the solubility of poorly absorbed drugs.
- Reduced toxicity: The metal can act as a “guardian”, releasing the active substance only in the target area of the body.
- New mechanisms of action: Unique magnetic and spectral properties of metal ions allow their use in diagnostics and photodynamic therapy.

The biological role of iron and copper

Iron and copper are essential micronutrients. They participate in key biochemical processes, ensuring the normal functioning of the body.

Iron - This The most common element, it plays an important role in the physiology of plants, animals, and humans. The main depots are erythrocytes, liver, spleen, and bone marrow. Iron deficiency in plants disrupts nitrogen and mineral metabolism, in animals causes microcytic anemia, and in humans, alimentary anemia—a decrease in hemoglobin levels. 60-72% of the iron contained in the human body is found in hemoglobin in the form of a chelate complex with protoporphyrin — heme. Hemoglobin performs two biological functions: it binds oxygen molecules and transports them from the lungs to the muscles, where they are passed on to myoglobin molecules; hemoglobin then uses several amino groups to bind carbon dioxide molecules and transports them back to the lungs. Depending on the bound ligand, iron is in one or another valence state: Fe 2+ —in hemoglobin, myoglobin; Fe 3+ —in catalase, oxidases. A large number of iron-containing proteins are known in nature. They participate in oxidation -reduction reactions, transfer electrons during photosynthesis, nitrogen and oxygen fixation, etc. They are part of oxidative enzymes, transporting electrons (catalase, peroxidase, cytochrome, etc.); they are part of the active center of a number of other enzymes (hydrolases, superoxide dismutases);

Iron also stimulates intracellular metabolic processes and is a component of protoplasm and cell nuclei; transferrin is a component of lymphocytes;

The body of a person weighing 70 kg contains 4.2 g of iron; in the blood – 447 mg/l; in bone tissue – 0.03-3.8 x 10 –2 %; in muscle tissue – 1.8 x 10 –2 %

I. Complex compounds of iron

By 2026, the use of iron complexes in pharmacology and medicine will have reached a high level of technological sophistication. The primary focus is on improving the safety and bioavailability of drugs, as well as their use in oncology and diagnostics.

1. Therapy of iron deficiency conditions

Currently, preference is given to coordination compounds over simple salts due to their better tolerance and the absence of a pronounced metallic taste.

- Chelated forms (Fe^{2+}): Iron bisglycinate is recognized as one of the most effective forms for oral administration. It has up to 90% bioavailability and minimal irritation to the gastrointestinal mucosa.
- Polysaccharide complexes (Fe^{3+}): Iron (III) hydroxide polymaltose remains the standard for long-term therapy, providing controlled release of iron without the risk of overdose.
- Iron Maltol: This complex, approved for general use, effectively crosses the intestinal barrier and is suitable for patients with inflammatory bowel disease.
- Liposomal iron: The technology of encapsulating iron in liposomes allows for complete avoidance of metal contact with the mucous membrane, which eliminates side effects in the stomach.

2. Parenteral administration (intravenous forms)

For rapid correction of severe anemia (for example, before surgery or in oncology), third-generation complexes are now used:

- Iron carboxymaltose (Ferinject): Allows high doses of iron (up to 1000 mg) to be delivered in a single infusion by mimicking the structure of natural ferritin.
- sucrose and dextrans: Used in the hospital sector for the treatment of chronic kidney disease and severe forms of iron deficiency.

3. Use in oncology and diagnostics

- Cuproptosis and ferroptosis: Iron complexes capable of selectively inducing cuproptosis have been actively studied recently. ferroptosis (programmed death) of cancer cells resistant to conventional chemistry.
- MRI contrast: Iron oxide nanoparticles coated with polymers are used as biocompatible contrast agents,

superior in safety to traditional gadolinium preparations.

4. Current trends (2025–2026)

By 2026, the use of iron complexes in pharmaceuticals will cover a wide range of areas—from classic deficiency replenishment to high-precision diagnostics and innovative therapy.

- gadolinium for imaging tumors and metastases.

New directions and technologies (2025–2026)

- Liposomal iron: The use of liposomes (fat capsules) to deliver iron complexes avoids contact of the metal with the gastric mucosa, which completely eliminates side effects.

- Development of new drugs: In 2026, the launch of new research and development centers for the synthesis of innovative metal complexes with desired properties is planned.

- Computer modeling: The use of AI-based systems (e.g., MetalloDock, updated in 2026) allows for highly accurate prediction of the interaction of iron complexes with biological targets.

II. Complex compounds of copper

Copper is a trace element that is essential for the functioning of the body. Physiological depots include the liver, bones, and brain. In living cells, copper is almost entirely complexed with protein.

Copper can inactivate the enzyme that catalyzes the destruction of insulin - insulinase. Copper is a part of oxidases, superoxide dismutase, participates in iron metabolism and antioxidant protection, is a catalyst for a number of cellular processes, especially carbohydrate metabolism; enhances water, gas and mineral metabolism. Copper increases the activity of some hormones, participates in enzymatic oxidation, tissue respiration, immune processes, pigmentation, is part of copper-containing enzymes and enzymes (cytochrome oxidase, etc.), vitamin B 1. Copper blocks SH-groups of proteins and enzymes (pepsin, amylase, etc.), forms complexes with proteins - cuproproteins (cytochrome oxidase, ceruloplasmin, etc.), participates in hematopoiesis (erythropoiesis, heme synthesis), stimulates the endocrine glands, has an insulin-like effect, increases the permeability of mitochondrial membranes.

The body of a person weighing 70 kg contains 72 mg copper; in the blood – 1.01 mg/l; in bone tissue – (1-26) · 10 –4 %; in muscle tissue – 1 · 10 –3 %.

Copper compounds exhibit pronounced antibacterial, anti-inflammatory, and antitumor activity. Copper complexes with amino acids, peptides, and nitrogen-containing ligands are studied as:

- antimicrobial agents,

- angiogenesis inhibitors,

- agents for tumor therapy.

Of particular interest are copper complexes capable of inducing apoptosis of tumor cells by generating reactive oxygen species.

The use of copper complexes in pharmaceuticals has become one of the most promising areas in the development of next-generation targeted drugs. Due to their ability to participate in redox processes and high biocompatibility, copper (II) compounds are finding application in the treatment of the most complex diseases.

1. Antitumor therapy (Cuproptosis)

A major breakthrough in recent years (2024–2026) has been the use of copper to induce cuproptosis , a specific mechanism of programmed cell death caused by copper accumulation. This allows for the destruction of cancer cells resistant to traditional chemotherapy.

Mechanisms of action: Copper complexes damage the DNA of cancer cells, inhibit enzymes (topoisomerases and proteasomes) and cause destructive oxidative stress through the generation of reactive oxygen species (ROS).

2. Theranostics and nuclear medicine

Radiopharmaceuticals have been actively developed in recent years. based on copper isotopes (e.g. 64 Cu and 67 Cu).

- Diagnosis and treatment: Copper isotopes allow for simultaneous visualization of the tumor using PET-CT and local radiation therapy.

- Neurology: Copper complexes are being studied for the diagnosis and modulation of the course of Alzheimer's and Parkinson's diseases.

3. Antimicrobial and antimycotic activity

Copper complexes effectively combat antibiotic-resistant " superbugs ".

- Synergy with antibiotics: In 2021–2025, copper complexes with known drugs (for example, fluconazole) were created, which significantly enhance their effect against fungal infections (Candida) and bacteria (Pseudomonas aeruginosa).

- Mechanism of attack: Copper ions from the complexes disrupt the functioning of proteins and metabolic pathways of microorganisms, to which bacteria do not have a developed defense system.

4. Application in dermatology and regeneration

Due to copper's ability to stimulate collagen and elastin synthesis, copper complexes (for example, copper peptides) are widely used in:

- Wound healing ointments: For the treatment of inflammatory processes of the mucous membranes and skin.

- Anti-inflammatory drugs: As an alternative to non-steroidal anti-inflammatory drugs (NSAIDs) with fewer side effects.

4. Conclusion

Pharmaceuticals have now transitioned from using simple copper salts to complex coordination compounds with organic ligands. This has improved drug stability in the bloodstream and ensured their precise delivery to affected tissues, minimizing overall toxicity to the body.

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