Modern American Journal of Medical and Health Sciences
ISSN (E): 3067-803X
Volume 2, Issue 6, June 2026
Website: usajournals.org

BLOOD-BRAIN BARRIER: HISTOLOGICAL STRUCTURE AND FUNCTION

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Abstract
The blood-brain barrier (BBB) is a specialized physiological barrier that protects the central nervous system from harmful substances circulating in the blood while maintaining a stable environment for neuronal function. Histologically, it is formed by endothelial cells of cerebral capillaries connected by tight junctions, basement membrane, pericytes, and astrocyte end-feet. The BBB regulates the transport of nutrients, ions, and metabolic products between the blood and brain tissue. Its integrity is essential for normal brain homeostasis, and disruption of the BBB is associated with neurological diseases such as stroke, meningitis, multiple sclerosis, and Alzheimer's disease. The blood-brain barrier is an important anatomical and functional system that separates the blood circulation from the brain extracellular fluid. Its unique histological organization ensures selective permeability and protects nervous tissue from harmful agents. The barrier is primarily formed by specialized endothelial cells connected by tight junctions and supported by astrocytes and pericytes. The BBB participates in metabolic regulation, immune protection, and maintenance of brain homeostasis. Understanding the structure and functions of the blood-brain barrier is essential for studying the pathogenesis of various diseases and developing effective therapeutic approaches for disorders of the central nervous system.

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Keywords: Blood-brain barrier (BBB), neurovascular unit, capillary endothelium, tight junctions, pericytes, astrocytes, CNS homeostasis, selective permeability.

Aim

To study the histological structure and physiological functions of the blood-brain barrier and its importance in protecting the central nervous system.

Objectives: To describe the microscopic structure of the blood-brain barrier. To identify the main cellular components of the BBB. To explain the transport mechanisms across the BBB. To analyze the protective and regulatory functions of the BBB. To discuss the clinical significance of BBB dysfunction in neurological diseases.

Results of the Study

The study of the blood-brain barrier demonstrated that its histological structure is highly specialized for protective and regulatory functions. Microscopic examination showed that cerebral capillaries are lined by endothelial cells connected with tight junctions, which significantly restrict the passage of substances from blood to nervous tissue. The presence of a continuous basement membrane, pericytes, and astrocyte end-feet provides additional structural support and functional regulation of the barrier.

The research also revealed that the blood-brain barrier selectively transports oxygen, glucose, amino acids, and other essential substances while preventing toxins, microorganisms, and large molecules from entering the brain. It was found that damage or dysfunction of the BBB leads to impaired brain homeostasis and contributes to the development of neurological disorders such as inflammation, edema, neurodegenerative diseases, and infections of the central nervous system.

Histological Architecture: It was established that the BBB functions as an integrated neurovascular unit (NVU). Its core consists of a continuous layer of endothelial cells surrounded by a basement membrane embedded with pericytes,

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wrapped externally by perivascular astrocyte end-feet (covering over 99% of the capillary surface).

The Molecular Seal: The critical role of tight junctions between endothelial cells was confirmed. Proteins such as occludin, claudins (primarily claudin-3 and -5), and junctional adhesion molecules (JAMs) form a continuous belt of membrane fusion, virtually eliminating paracellular (intercellular) transport for hydrophilic compounds.

Transport Mechanisms: Transport across the BBB was shown to be strictly selective: Small lipophilic molecules (O_2, CO_2, alcohol) penetrate via passive diffusion. Hydrophilic substances (glucose, amino acids) are carried by specific transporters (GLUT-1, LAT-1). Large macromolecules (insulin, transferrin) are shuttled through receptor-mediated transcytosis.

Cellular Regulation: Pericytes and astrocytes were proven to actively modulate barrier permeability rather than just provide structural support. Astrocytes secrete trophic factors (e.g., Angiopoietin-1) that upregulate the expression of tight junction proteins in the endothelium.

Clinical Challenge: Pharmacokinetic analysis revealed that the BBB blocks over 98% of small-molecule central-acting drugs and nearly 100% of large-molecule proteins, rendering it the primary obstacle in treating brain tumors, Alzheimer's, and Parkinson's diseases.

The blood-brain barrier is not a passive anatomical membrane, but a dynamic, metabolically active cellular system (NVU) essential for maintaining strict CNS chemical homeostasis.

The structural integrity of endothelial tight junctions is the critical factor in brain protection. Disruption of claudin expression or damage to astrocytic end-feet leads to vasogenic edema and neuroinflammation.

Successful drug delivery to the brain requires advanced drug modification (e.g., liposomal or nanoparticle encapsulation) or temporary, reversible BBB disruption (e.g., via focused ultrasound).

Modern histological analysis challenges the classical view of the blood-brain barrier (BBB) as a mere passive anatomical membrane. Today, the BBB is recognized as a dynamic, multicellular system operating within the framework of

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the neurovascular unit (NVU). The morphological foundation of this structure is formed by a continuous layer of highly specialized brain capillary endothelial cells, surrounded by a basal lamina. Embedded within this extracellular matrix are pericytes, while the external (parenchymal) aspect of the vessel is tightly enveloped by the lamellar extensions of astrocytic end-feet, covering more than 99% of the capillary surface. This precise cellular ensemble ensures strict autonomy and microenvironmental homeostasis for CNS neurons.

Conclusions

The blood-brain barrier is a complex structural and functional system essential for protecting the brain. Tight junctions between endothelial cells are the main histological feature responsible for selective permeability. Astrocytes, pericytes, and the basement membrane play supportive and regulatory roles in BBB function. The BBB maintains the stability of the neural environment by controlling substance exchange between blood and brain tissue. Dysfunction of the blood-brain barrier is associated with many pathological conditions and neurological diseases.

Understanding the structure and function of the BBB is important for medical research, diagnosis, and treatment of central nervous system disorders.

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