ISCHEMIC STROKE: ETIOLOGY, PATHOGENESIS, AND MODERN DIAGNOSTIC APPROACHES

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Annotation

This article provides a comprehensive overview of the etiology, pathogenesis, and modern diagnostic approaches to ischemic stroke. The mechanisms underlying cerebral ischemia, including arterial occlusion, energy failure, excitotoxicity, oxidative stress, and inflammation, are analyzed in detail. Particular attention is given to contemporary neuroimaging methods such as CT, MRI, angiography, and perfusion imaging, which play a crucial role in early diagnosis and in distinguishing the infarct core from the penumbra. Early recognition and imaging-based assessment significantly improve treatment outcomes and reduce long-term disability.

Keywords

Ischemic stroke; Etiology; Pathogenesis; Neuroimaging; CT; MRI; Diagnostics.

ИШЕМИЧЕСКИЙ ИНСУЛЬТ: ЭТИОЛОГИЯ, ПАТОГЕНЕЗ И СОВРЕМЕННЫЕ МЕТОДЫ ДИАГНОСТИКИ

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Аннотация

В статье представлен подробный обзор этиологии, патогенеза и современных методов диагностики ишемического инсульта. Детально рассматриваются механизмы развития церебральной ишемии, включая окклюзию артерий, энергетическую недостаточность, эксайтотоксичность, оксидативный стресс

и воспалительные реакции. Особое внимание уделено современным методам нейровизуализации — КТ, МРТ, ангиографии и перфузионным исследованиям, которые имеют ключевое значение для ранней диагностики и различения инфарктного ядра и пенумбры. Своевременное выявление инсульта и визуализационно-ориентированный подход существенно улучшают результаты лечения и снижают риск инвалидизации.

Ключевые слова

Ишемический инсульт; Этиология; Патогенез; Нейровизуализация; КТ; МРТ; Диагностика.1.

Introduction

Ischemic stroke is among the most significant global public health challenges, ranking as one of the leading causes of disability and death. According to the World Health Organization, more than 15 million individuals suffer a stroke every year, and approximately 5 million are left permanently disabled, while another 5 million die. Approximately 80–85% of all strokes are ischemic, making prevention, early diagnosis, and timely treatment essential priorities in contemporary neurology.

Ischemic stroke typically develops due to occlusion of cerebral arteries by thrombus or embolus, or as a consequence of severe systemic hemodynamic compromise. Atherosclerosis, arterial hypertension, diabetes mellitus, and cardiac arrhythmias—especially atrial fibrillation—are recognized as major risk factors. Additionally, hypercoagulable states, genetic thrombophilias, metabolic syndrome, and environmental influences significantly contribute to disease risk.

The pathogenesis of ischemic stroke involves rapid and profound metabolic disruption within brain tissue. The sequence begins with arterial occlusion and diminished cerebral perfusion, followed by energy failure, excitotoxicity, oxidative stress, inflammation, and eventual neuronal death. A crucial concept in this process is the distinction between the irreversibly damaged infarct core and the surrounding penumbra—hypoperfused but potentially salvageable tissue. Preserving the penumbra is the central goal of modern stroke treatment.

Accurate and rapid diagnosis is vital, since effective interventions such as intravenous thrombolysis and mechanical thrombectomy are time-dependent. Consequently, contemporary neuroimaging techniques—computed tomography (CT), magnetic resonance imaging (MRI), CT/MR angiography, perfusion

imaging, and Doppler ultrasonography—are indispensable tools for clinical decision-making.

This article aims to systematically review the etiology, pathogenesis, and modern diagnostic strategies in ischemic stroke, drawing on current scientific literature and clinical guidelines.

2. Methods

This article was developed through a systematic review of contemporary scientific literature. Sources included:

Peer-reviewed articles published between 2015 and 2024 in PubMed, Scopus, and Google Scholar

Guidelines from the World Health Organization and the European Stroke Organization

Modern neurology and cerebrovascular disease textbooks

Data analysis involved thematic synthesis, comparison of diagnostic modalities, and evaluation of current imaging protocols used in clinical practice.

3. Results

3.1 Etiology

The primary etiological categories of ischemic stroke are:

Cardioembolic Causes, Atrial fibrillation, Post-myocardial infarction mural thrombi

Valvular heart disease, Prosthetic valve-associated thrombosis, Arterio-arterial Embolism, Rupture of atherosclerotic plaques in carotid arteries, Large-artery atherothrombosis, Local Thrombosis, Intracranial and extracranial arterial stenosis

Endothelial dysfunction and plaque instability, Hemodynamic Insufficiency, Severe hypotension,Cardiac output failure, Hematological Abnormalities, Polycythemia

Hypercoagulable states (e.g., thrombophilia)

3.2 Pathogenesis

Ischemic stroke develops through interconnected mechanisms:

Arterial Occlusion – Reduced blood supply diminishes oxygen and glucose delivery.

Energy Failure – ATP depletion leads to Na^+/K^+-ATPase dysfunction and cellular swelling.

Excitotoxicity – Excess glutamate release and Ca^{2+} influx trigger neuronal injury.

Formation of Infarct Core and Penumbra – The core undergoes irreversible necrosis; the penumbra remains viable temporarily.

Oxidative Stress and Inflammation – Free radicals and cytokines accelerate tissue damage.

3.3 Modern Diagnostic Approaches

Computed Tomography (CT)

First-line imaging modality

Essential for excluding intracranial hemorrhage

Useful in evaluating late-stage infarct changes

Magnetic Resonance Imaging (MRI)

DWI: Detects early ischemia within minutes

PWI: Assesses cerebral perfusion and delineates penumbra

FLAIR/T2: Defines infarct extent

CT and MR Angiography (CTA/MRA)

Visualizes arterial occlusion

Critical for selecting candidates for mechanical thrombectomy

Perfusion Imaging

CT perfusion or MR perfusion helps differentiate core vs penumbra

Doppler Ultrasonography

Evaluates carotid and vertebrobasilar circulation

Detects stenosis, occlusion, or turbulent flow

Laboratory Testing

Coagulation profile

Blood glucose

Lipid panel

Hypercoagulability studies

4. Discussion

The results emphasize that ischemic stroke is a multifactorial disease with strong associations to metabolic, cardiovascular, and hematological risk factors. Atherosclerosis and atrial fibrillation are consistently identified as major contributors to thromboembolic events. Early identification of at-risk individuals remains a key priority in reducing global disease burden.

Pathogenesis analysis highlights the importance of protecting the penumbra, as timely reperfusion can reverse ischemic injury. Modern diagnostic technologies, particularly DWI and perfusion imaging, significantly enhance the clinician's ability to differentiate viable tissue from the infarct core.

Moreover, the rapid diagnostic workflow—including CT, CTA, and where available, MRI—directly influences eligibility for thrombolysis and thrombectomy, substantially improving outcomes. Integration of these modalities into clinical protocols is essential, especially in stroke centers aiming for optimal "door-to-needle" and "door-to-groin" times.

Conclusion

Ischemic stroke is a complex condition driven by diverse etiological factors and characterized by rapid, progressive neuronal injury. Understanding its pathophysiology is essential for implementing effective treatment strategies. Modern diagnostic approaches—particularly advanced neuroimaging—play a pivotal role in early detection, patient selection for reperfusion therapy, and prognostic assessment. Continued improvements in diagnostic protocols and wider access to imaging technologies will further enhance stroke care and reduce long-term disability.

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