

Emerging Therapeutic Strategies in Ischemic and Hemorrhagic Stroke

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Introduction

Stroke remains one of the leading causes of mortality and long-term disability worldwide, posing a major challenge to healthcare systems and societies. Broadly categorized into ischemic and hemorrhagic types, stroke arises from distinct yet devastating pathophysiological mechanisms ischemic stroke due to cerebral vessel occlusion and hemorrhagic stroke due to vessel rupture and bleeding. OCurrent therapeutic options are limited by narrow treatment windows, risks of complications and insufficient efficacy in addressing secondary injury processes such as oxidative stress, excitotoxicity, inflammation and blood–brain barrier disruption. Emerging approaches include pharmacological agents targeting excitotoxic cascades, mitochondrial dysfunction and neuroinflammation; neurorestorative interventions such as stem cell therapies and neurotrophic factors; as well as advanced technologies like neurostimulation, nanomedicine and precision medicine guided by biomarkers and artificial intelligence. By exploring novel mechanisms and leveraging interdisciplinary innovations, emerging therapies hold the potential to transform the current landscape of stroke care. This article reviews the evolving strategies in both ischemic and hemorrhagic stroke management, highlighting their underlying principles, clinical potential and challenges in translation to routine practice [1].

Description

Stroke continues to represent one of the most significant global health challenges, ranking among the top causes of death and long-term disability. The burden of stroke is disproportionately high in low- and middle-income countries, where access to timely interventions remains limited. Broadly, strokes are classified as ischemic, resulting from an arterial occlusion, or hemorrhagic, caused by rupture of cerebral vessels leading to bleeding into or around brain tissue. Ischemic strokes account for nearly 80–85% of all cases, while hemorrhagic subtypes, though less common, are associated with higher rates of mortality and morbidity. Traditional treatments for ischemic stroke, such as intravenous thrombolysis with tissue plasminogen activator (tPA) and mechanical thrombectomy,

have revolutionized acute management but remain constrained by narrow therapeutic windows and strict eligibility criteria. Hemorrhagic strokes are often managed with surgical decompression, hematoma evacuation, or endovascular approaches, yet outcomes remain unsatisfactory in many patients. Both stroke types share complex secondary injury mechanisms involving excitotoxicity, oxidative stress, mitochondrial dysfunction, apoptosis and neuroinflammation. These approaches aim not only to improve acute survival but also to enhance long-term functional recovery and neuroplasticity [2].

Emerging pharmacological strategies in stroke therapy are targeting previously underexplored molecular pathways. Neuroprotective agents designed to limit excitotoxic damage, such as NMDA receptor antagonists and modulators of glutamate release, are showing promise in preclinical and early clinical studies. Anti-inflammatory agents, including monoclonal antibodies against interleukin-1 β and inhibitors of tumor necrosis factor- α , are also under investigation for their ability to modulate post-stroke inflammation. Pharmacogenomic approaches are being applied to personalize treatment selection based on genetic variations influencing drug metabolism and response. In addition, therapies that target blood–brain barrier integrity are gaining attention, as disruption of this barrier exacerbates edema and neuronal loss in both ischemic and hemorrhagic strokes. The repurposing of existing drugs, such as statins and angiotensin receptor blockers, for their neuroprotective and anti-inflammatory properties, represents another cost-effective strategy. While many of these approaches remain in experimental stages, they highlight a paradigm shift toward addressing stroke as a multifactorial disease process. Such strategies reflect the recognition that a single therapeutic target may be insufficient to counteract the complex pathophysiology of stroke [3].

Beyond pharmacological advances, regenerative and restorative therapies are emerging as critical avenues for stroke

management. Stem cell-based therapies, including mesenchymal stem cells, neural progenitor cells and induced pluripotent stem cells, are being evaluated for their capacity to promote neuronal repair, angiogenesis and immunomodulation. Robotic-assisted rehabilitation and virtual reality platforms are enhancing traditional physiotherapy approaches, providing personalized and intensive training for motor recovery. Neurorestorative therapies are particularly relevant for patients who survive the acute phase but face persistent functional impairments. The integration of these therapies into post-stroke care reflects a growing recognition that recovery is a dynamic and prolonged process requiring multimodal interventions. Importantly, these emerging strategies emphasize not only the repair of damaged tissue but also the enhancement of compensatory pathways to maximize functional independence. While challenges remain regarding scalability, cost and long-term safety, the promise of these restorative approaches is undeniable [4].

Technological innovation and precision medicine are increasingly shaping the future of stroke therapeutics. Artificial Intelligence (AI) and machine learning are being applied to improve early diagnosis, predict outcomes and guide personalized treatment decisions. Advanced neuroimaging techniques, including perfusion imaging and molecular imaging, are enabling better identification of salvageable brain tissue and tailoring of interventions. Biomarkers derived from blood, cerebrospinal fluid and neuroimaging are under development to stratify patients, monitor therapeutic response and predict recovery trajectories. Ultimately, the convergence of pharmacological, regenerative and technological innovations represents a holistic strategy for transforming stroke management. By targeting both acute events and long-term recovery, these emerging approaches hold the potential to reduce the global burden of stroke and improve the lives of millions worldwide [5].

Conclusion

The evolving landscape of stroke therapeutics reflects a paradigm shift from narrowly focused acute interventions to comprehensive, multi-targeted strategies that address both immediate vascular events and long-term neurological recovery. While traditional approaches such as thrombolysis, thrombectomy and surgical hematoma evacuation remain central pillars of stroke management, their limitations have

spurred the exploration of novel pharmacological, regenerative and technological solutions. Advances in neuroprotection, stem cell therapy, nanomedicine and neuromodulation illustrate the growing emphasis on repairing damage, restoring function and enhancing neuroplasticity. At the same time, innovations in artificial intelligence, precision medicine and digital health are reshaping how clinicians diagnose, stratify and monitor patients, ensuring that treatments are tailored to individual needs.

Acknowledgment

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Conflict of Interest

None.

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