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PHARMACOLOGICAL AND ENDOVASCULAR APPROCHES, SECONDARY PREVENTION, AND THE ROLE OF CLINICAL PHARMACISTS IN STROKE MANAGEMENT

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ABSTRACT
Stroke is one of the leading causes of mortality and long-term disability worldwide, with a significant impact on individuals and healthcare systems. Over the past decade, substantial progress has been made in the diagnosis, treatment, and prevention of stroke. This review summarizes recent advances in stroke management published between 2016 and 2026, with a focus on thrombolytic therapy, mechanical thrombectomy, advanced neuroimaging, artificial intelligence, telestroke services, neuroprotective strategies, and secondary stroke prevention. The review also highlights the expanding role of clinical pharmacists in optimizing pharmacotherapy, improving medication safety, promoting patient adherence, and supporting multidisciplinary stroke care. Emerging technologies and personalized treatment approaches have enhanced patient selection, reduced treatment delays, and improved functional outcomes. Despite these advances, challenges such as delayed hospital presentation, limited access to specialized stroke centers, and disparities in healthcare remain. Continued research, technological innovation, and implementation of evidence-based guidelines are essential to further improve stroke care and reduce the global burden of stroke. The objective of this review is to summarize the recent advances in stroke management, with a particular focus on pharmacological therapies, endovascular interventions, secondary prevention strategies, and the expanding role of clinical pharmacists in optimizing patient care and improving clinical outcomes.

Keywords: *Stroke, Acute ischemic stroke, Hemorrhagic, stroke,Tenecteplase, Mechanical thrombectomy, Secondary prevention, Clinical pharmacist, Thrombolysis, Neuroimaging.*

INTRODUCTION
Stroke is a major public health challenge and one of the leading causes of death and long-term disability worldwide. Besides its clinical impact, stroke imposes considerable economic costs through medical care, rehabilitation, and productivity loss, emphasizing the importance of effective prevention, early diagnosis, and timely management. [1]. Recovery after stroke is influenced by several interconnected factors that determine the patient's rehabilitation outcomes. Self-efficacy, or an individual's confidence in managing daily activities and recovery challenges, plays a key role in improving functional ability and promoting independence. Better functional recovery is associated with an improved quality of life, encompassing physical, psychological, and social well-being. At the same time, the degree of dependence on caregivers can affect a survivor's emotional health, self-esteem, and confidence during rehabilitation. Therefore, comprehensive stroke management should address not only physical recovery but also psychological support and patient-centered rehabilitation to enhance overall quality of life and long-term outcomes [2].

EPIDEMIOLOGY
Ischemic stroke is the most common type of stroke and occurs when blood flow to a specific area of the brain is interrupted, resulting in neurological dysfunction. It accounts for approximately 87% of all stroke cases [3]. Globally, stroke remains a major cause of morbidity and mortality. In 2020, an estimated 89.13 million people were living with stroke, with acute ischemic stroke accounting for approximately 68.16 million cases. During the same year, around 11.71 million new stroke cases were reported worldwide, of which nearly 65% were ischemic strokes, 29% were intracerebral hemorrhages, and 6% were subarachnoid hemorrhages. Stroke was responsible for approximately 7.08 million deaths globally, emphasizing the importance of early risk factor management, timely diagnosis, and evidence-based treatment to reduce its health and socioeconomic burden [4].

TYPES OF STROKE:

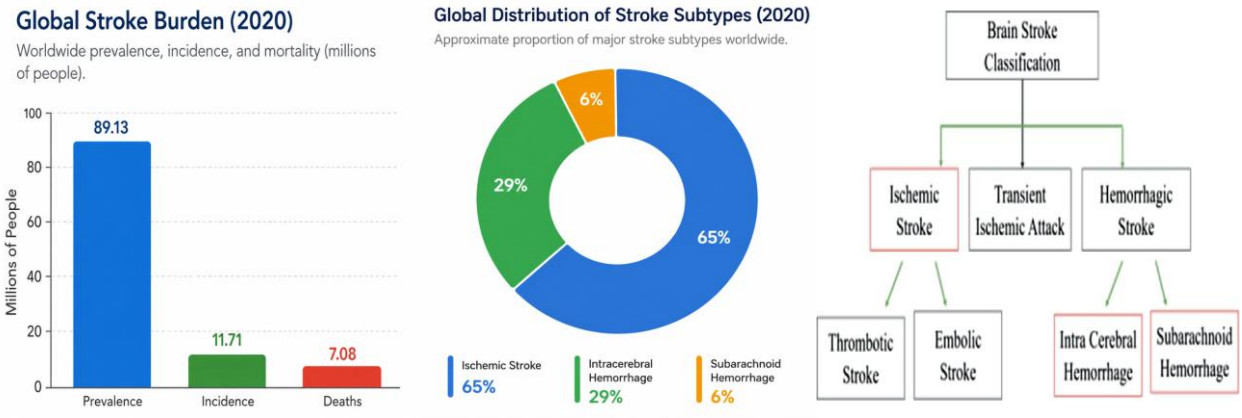

Figure 01: Global Stroke Burden and distribution of stroke sub types

1. Ischemic Stroke

Ischemic stroke is the most common type, accounting for approximately 85% of all stroke cases. It occurs when a cerebral artery is obstructed, leading to reduced blood flow and oxygen delivery to brain tissue.(5) The obstruction is usually caused by thrombosis, embolism, or small-vessel disease. The resulting ischemia triggers a cascade of events, including energy failure, excitotoxicity, oxidative stress, inflammation, and neuronal cell death [6].

2. Hemorrhagic Stroke

Hemorrhagic stroke accounts for approximately 15% of all strokes but is associated with higher mortality and greater neurological disability [7]. It occurs when a blood vessel ruptures, causing bleeding within or around the brain. The extravagated blood increases intracranial pressure, damages surrounding brain tissue, and disrupts cerebral perfusion [8].

3. Transient Ischemic Attack (TIA)

A transient ischemic attack is a brief episode of neurological dysfunction caused by temporary interruption of cerebral blood flow without evidence of permanent brain infarction. Symptoms usually resolve within one hour, although they may persist for up to 24 hours in some cases [9]. TIA is an important warning sign because it significantly increases the risk of a subsequent ischemic stroke. Prompt evaluation and initiation of preventive measures can substantially reduce this risk [10].

PATHOPHYSIOLOGY

Pathophysiology of Ischemic Stroke

An ischemic stroke occurs when a blood clot blocks a cerebral artery, reducing or stopping blood flow to the brain. This creates an area of irreversible tissue damage (ischemic core) surrounded by the ischemic penumbra, where brain cells remain viable if blood flow is restored quickly [11].

The loss of oxygen and glucose depletes ATP, leading to failure of ion pumps and abnormal neuronal depolarization. Excessive glutamate release causes increased calcium entry into neurons, activating enzymes that damage proteins, lipids, and DNA. In addition, oxidative stress and inflammation worsen cell injury through the release of reactive oxygen species and inflammatory mediators. Without timely reperfusion, these events result in neuronal death and lasting neurological impairment. [12].

Pathophysiology of Hemorrhagic Stroke

Hemorrhagic stroke results from rupture of a cerebral blood vessel, leading to bleeding into the brain parenchyma or subarachnoid space. (13)The accumulation of blood forms a hematoma that compresses surrounding brain tissue, increases intracranial pressure, and reduces cerebral perfusion. Hemoglobin degradation products and inflammatory mediators released from the hematoma contribute to secondary brain injury through oxidative stress, inflammation, disruption of the blood–brain barrier, and cerebral edema [14].

RECENT ADVANCES IN STROKE MANAGEMENT

1. Tenecteplase: (Intravenous fibrinolytics)

Intravenous thrombolysis remains the cornerstone of treatment for eligible patients with acute ischemic stroke. While alteplase has long been the standard thrombolytic agent within 4.5 hours of symptom onset, recent evidence has established tenecteplase as an effective alternative. Clinical trials and meta-analyses have demonstrated that tenecteplase provides equal or superior functional outcomes compared with alteplase, particularly in patients with large-vessel occlusion undergoing mechanical thrombectomy [15].

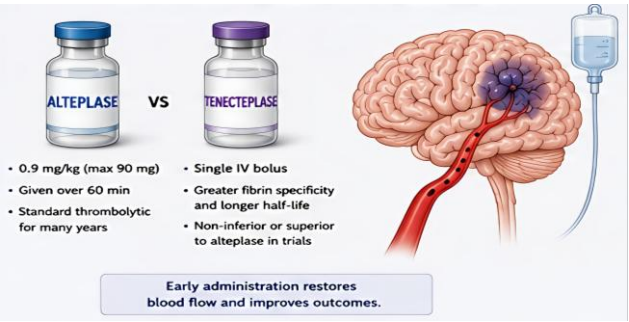

Figure 02: Intravenous Thrombolytics

Pharmacokinetics and Pharmacodynamics of Tenecteplase

Thrombolytic therapy restores cerebral blood flow by dissolving the clot that blocks an artery. This is achieved when tissue plasminogen activator (tPA) converts plasminogen into plasmin, an enzyme that breaks down fibrin within the thrombus, enabling vessel recanalization [16]. Tenecteplase is a modified form of tPA with several advantages over alteplase. Its longer half-life allows it to be given as a single intravenous bolus, simplifying administration and reducing treatment delays. It also has greater fibrin specificity and improved resistance to plasminogen activator inhibitor-1 (PAI-1), promoting more targeted clot breakdown and potentially improving recanalization while reducing the risk of bleeding. These features make tenecteplase an effective alternative for the treatment of acute ischemic stroke [17].

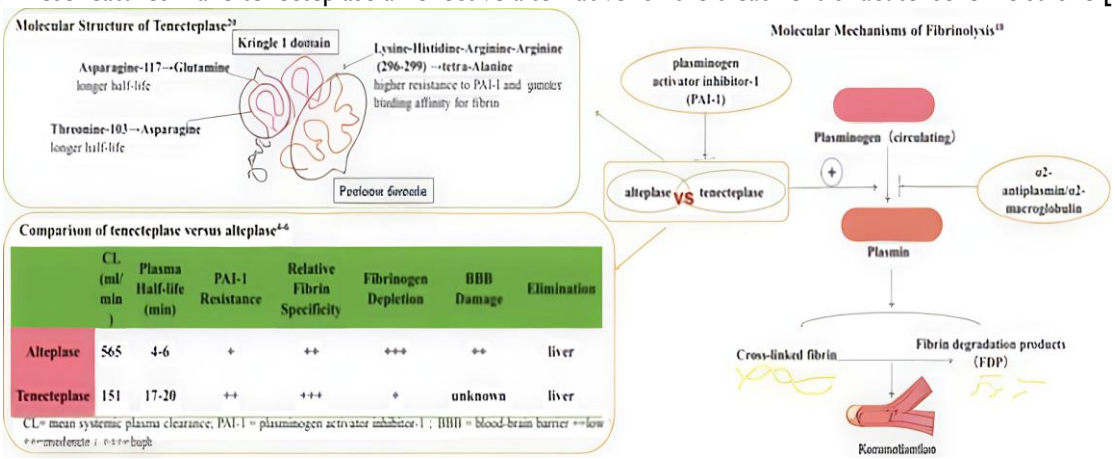

Figure 03: Pharmacokinetics and Pharmacodynamics of Tenecteplase

2. Mechanical Thrombectomy

MechaMechanical thrombectomy is an effective treatment for acute ischemic stroke caused by large-vessel occlusion. The procedure removes the clot through endovascular techniques using stent retrievers, aspiration catheters, or both, restoring blood flow to the affected brain region. It is now the standard treatment for eligible patients with anterior circulation large-vessel occlusion [18]. Although initially recommended within six hours of symptom onset, evidence has shown that carefully selected patients with favorable imaging findings can benefit from thrombectomy up to 24 hours after stroke onset. Advances in thrombectomy devices have improved recanalization rates and reduced complications, and the procedure is also beneficial in selected patients with basilar artery occlusion and large ischemic core infarction [19].

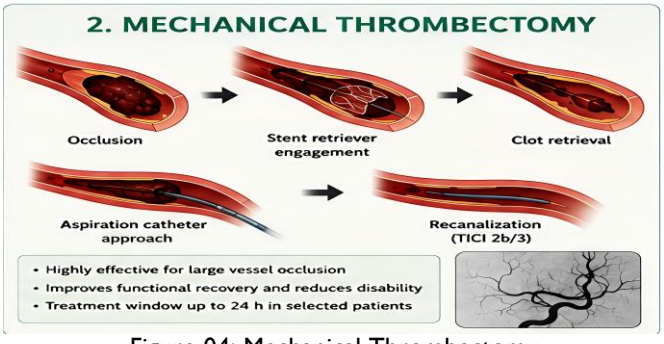

Figure 04: Mechanical Thrombectomy

3. Advanced Neuroimaging

Advances in neuroimaging have transformed stroke diagnosis and treatment selection. Non-contrast computed tomography remains the first-line imaging modality for differentiating ischemic and hemorrhagic stroke. However, modern stroke management increasingly relies on CT angiography, CT perfusion, diffusion-weighted MRI, and perfusion

MRI.(20)These imaging techniques help identify large-vessel occlusion, estimate infarct core size, evaluate collateral circulation, and detect the ischemic penumbra. As a result, clinicians can identify patients most likely to benefit from thrombolysis or thrombectomy, even beyond conventional treatment windows. Imaging-guided decision-making has significantly improved patient selection and clinical outcomes [21].

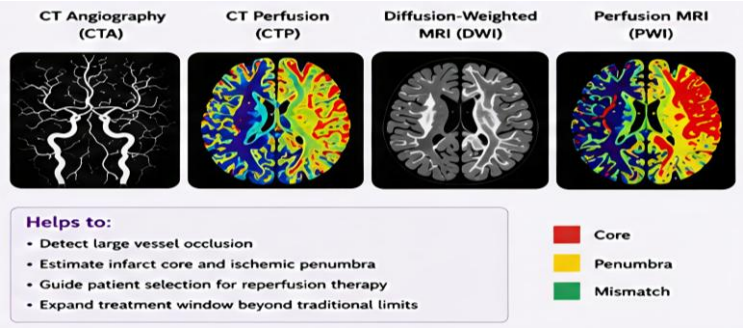

Figure 05: Advance Neuroimaging

4. Artificial Intelligence in Stroke Care

Artificial intelligence has emerged as an important tool in stroke management. AI-powered software can rapidly analyze brain scans, identify intracranial hemorrhage, detect large-vessel occlusion, and estimate infarct core and penumbra volumes [22]. These systems reduce interpretation time and assist clinicians in making faster treatment decisions. Machine-learning models are also being developed to predict functional outcomes, assess treatment response, and support individualized patient management. [23]. AI-assisted technologies are increasingly integrated into emergency stroke pathways and may further improve treatment efficiency and patient outcomes in the future [24].

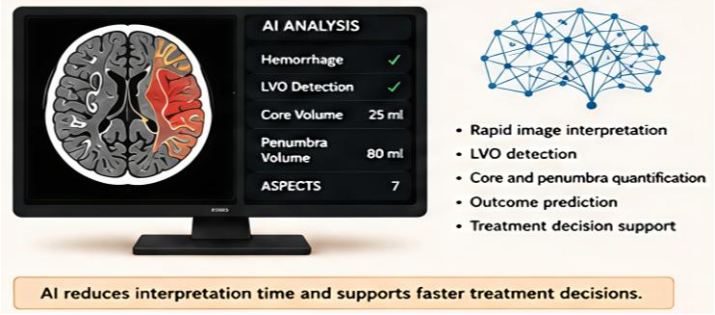

Figure 06: Artificial Intelligent in Stroke Care

5. Telestroke and Mobile Stroke Units

Telemedicine has substantially improved access to specialist stroke care, particularly in rural and underserved areas. Telestroke programs enable remote consultation with stroke neurologists, facilitating rapid diagnosis and treatment decisions. These networks have increased thrombolysis rates and reduced delays in treatment. (25)Mobile stroke units equipped with CT scanners, telemedicine capabilities, and laboratory testing allow diagnosis and initiation of therapy before hospital arrival. Studies have demonstrated reductions in treatment times and improved functional outcomes among patients managed through mobile stroke units [26].

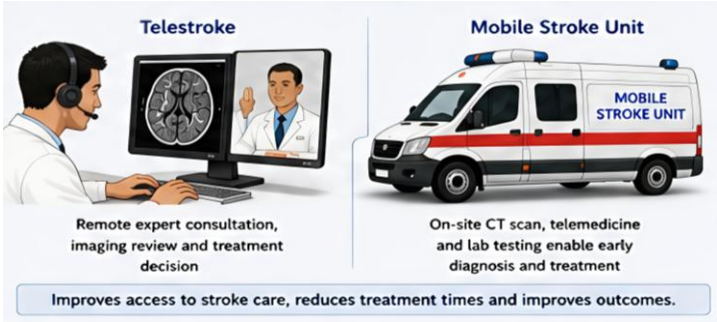

Figure 06: Telestroke and Mobile Stroke Unit

6.Emerging Neuroprotective and Regenerative Therapies

Although reperfusion therapy remains the primary treatment strategy, substantial research is focused on neuroprotective therapies designed to limit neuronal injury during ischemia. Investigational approaches target excitotoxicity, oxidative stress, inflammation, apoptosis, and mitochondrial dysfunction. Regenerative therapies such as stem-cell therapy, extracellular vesicles, exosome-based treatments, and neurorestorative interventions are also being

explored. While many of these approaches remain experimental, they represent promising future directions for enhancing neurological recovery and improving long-term outcomes after stroke [27].

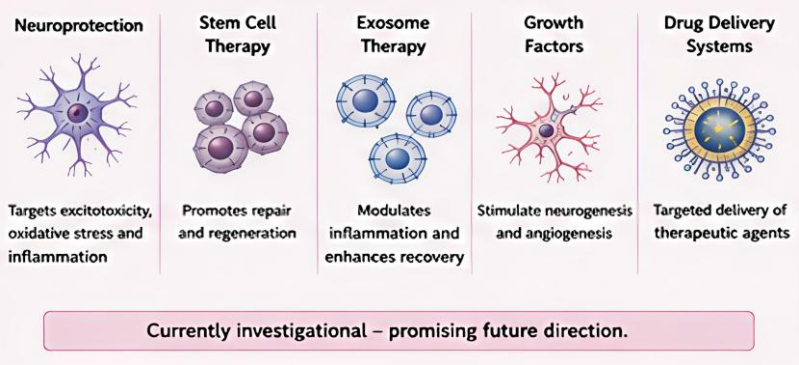

Figure 07: Emerging Neuroprotective and Regenerative Therapies

SECONDARY PREVENTION OF STROKE

Secondary prevention focuses on preventing recurrent stroke and other cardiovascular complications after an ischemic stroke or transient ischemic attack (TIA). Management should be tailored to the patient's stroke type and individual risk factors through a combination of appropriate medications, risk factor control, healthy lifestyle practices, and regular follow-up [28]

Antiplatelet therapy is recommended for non-cardioembolic stroke, while anticoagulants are preferred for cardioembolic stroke associated with atrial fibrillation. Lipid-lowering therapy, effective blood pressure control, and optimal diabetes management are essential to reduce future vascular risk. Lifestyle measures such as quitting smoking, limiting alcohol intake, maintaining a balanced diet, regular physical activity, and achieving a healthy weight further support stroke prevention [29]. In selected patients with symptomatic carotid artery stenosis, carotid revascularization procedures may be indicated. Ongoing rehabilitation, patient education, and adherence to prescribed treatment are also vital for improving recovery and reducing the likelihood of recurrent stroke [30].

Role of the Clinical Pharmacist in Stroke Management

Clinical pharmacists play a vital role in stroke management by ensuring safe and effective medication use across all stages of care, from acute treatment to rehabilitation and long-term prevention [31]. They review medication histories, identify stroke risk factors, optimize drug therapy, and support the timely administration of thrombolytic agents while monitoring for adverse effects [32)].

During hospitalization and follow-up, pharmacists help prevent medication errors, monitor treatment outcomes, and optimize the use of antiplatelet, anticoagulant, antihypertensive, lipid-lowering, and antidiabetic therapies [33].They also educate patients and caregivers on medication adherence, lifestyle modifications, and recognition of stroke warning signs, while performing medication reconciliation during care transitions. Through collaboration with the multidisciplinary healthcare team, participation in research, and quality improvement initiatives, clinical pharmacists enhance medication safety, reduce the risk of recurrent stroke, and improve overall patient outcomes [34.

FUTURE PERSPECTIVES

Future stroke management is expected to focus on improving reperfusion therapies, developing neuroprotective strategies, and advancing personalized treatment approaches [35]. Technologies such as artificial intelligence, precision medicine, telemedicine, and enhanced endovascular procedures are likely to improve diagnosis, treatment, and recovery. Emerging therapies, including stem cell and regenerative medicine, may further enhance neurological outcomes [36]. The increasing role of clinical pharmacists in medication optimization and patient care will strengthen evidence-based practice, while continued research and innovation are expected to reduce stroke-related disability and improve patients' quality of life [37].

CONCLUSION

Stroke continues to be a leading cause of death and long-term disability worldwide, although major advances in diagnosis and treatment have improved patient outcomes. Modern therapies, including thrombolysis, mechanical thrombectomy, and advanced imaging, have enhanced the management of acute ischemic stroke, while secondary prevention through appropriate medications, risk factor control, and healthy lifestyle practices helps reduce recurrence. Multidisciplinary care, with an important contribution from clinical pharmacists, supports safe medication use, patient education, and treatment adherence. Although challenges such as delayed access to care and healthcare disparities persist, ongoing innovations in artificial intelligence, precision medicine, telemedicine, and stroke research are expected to further improve stroke prevention, treatment, and overall patient outcomes.

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