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## STROKE TREATMENT

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**ABSTRACT**

**Introduction.** Stroke is a major cause of death and disability worldwide. Effective management requires rapid reperfusion, secondary prevention, and appropriate rehabilitation. This paper reviews thrombolysis, thrombectomy, atorvastatin therapy, VR-based rehabilitation, and emerging exosome-based treatment as selected approaches to stroke management.

**Materials and methods.** Relevant literature was identified through a structured search of PubMed and Google Scholar databases. The search included terms such as “Stroke treatment,” followed by more specific phrases related to VR rehabilitation, thrombolysis, thrombectomy, treatment using exosomes, atorvastatin and surgical treatment. The analysis primarily included systematic reviews, meta-analyses, and randomized controlled trials in accordance with Evidence-Based Medicine (EBM) principles.

**Results.** The reviewed treatments demonstrated beneficial effects at different stages of stroke management. Thrombolysis and thrombectomy improved reperfusion and functional outcomes in appropriately selected patients. Atorvastatin reduced the risk of recurrent vascular events and supported secondary prevention. VR-based rehabilitation showed potential to improve motor function, balance and mobility. Exosome-based therapy demonstrated promising neuroprotective and regenerative effects, although current evidence remains predominantly preclinical.

**Conclusions.** Stroke treatment requires a comprehensive approach combining acute reperfusion, secondary prevention and rehabilitation. Thrombolysis and thrombectomy remain essential for eligible patients, while atorvastatin supports secondary prevention. VR-based rehabilitation may enhance functional recovery, and exosome therapy represents a promising emerging approach. Further research is needed to establish the long-term efficacy and clinical application of newer therapies.

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**KEYWORDS**

Stroke Treatment, VR Rehabilitation Used in Stroke Treatment, Atorvastatin in Stroke Treatment, Thrombolysis and Thrombectomy as Stroke Treatment, Treating Stroke Using Exosomes

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**Introduction.**

Stroke is a major neurological disorder and one of the leading causes of death and long-term disability worldwide. It occurs when cerebral blood flow is interrupted, most commonly as a result of arterial occlusion in ischemic stroke or vessel rupture in haemorrhagic stroke. The resulting disruption of oxygen and nutrient delivery can cause irreversible brain damage, making early diagnosis and appropriate treatment essential for improving clinical outcomes. (Alonso de Leciñana et al., 2014; De Santis et al., 2026)

The management of ischemic stroke has developed substantially over recent decades. Acute reperfusion therapies, particularly intravenous thrombolysis and mechanical thrombectomy, aim to restore cerebral blood flow and limit the extent of brain injury. Their effectiveness is strongly dependent on rapid patient assessment, appropriate patient selection and timely initiation of treatment. (Ho & Powers, 2024; De Santis et al., 2026; Zi et al., 2021)

In addition to acute interventions, secondary prevention is essential for reducing the risk of recurrent cerebrovascular events. High-intensity statin therapy, particularly atorvastatin, has demonstrated efficacy in reducing the risk of recurrent stroke and major cardiovascular events following ischemic stroke or transient ischemic attack. (Amarenco et al., 2006; Hulsa et al., 2010)

Recovery after stroke frequently requires prolonged rehabilitation because patients may experience persistent motor, cognitive, sensory and functional impairments. Conventional rehabilitation can be complemented by emerging technologies such as virtual reality (VR), which may increase the intensity, repetition and engagement of task-oriented exercises and may support improvements in motor function, balance and functional mobility. (Peláez-Vélez et al., 2023; Chen et al., 2022; Wu et al., 2021)

At the same time, advances in regenerative medicine have led to increasing interest in experimental approaches such as exosome-based therapy. Exosomes may contribute to neuroprotection and tissue repair

through the transfer of biologically active molecules and modulation of processes such as inflammation, apoptosis, angiogenesis and neuroplasticity. However, most evidence remains preclinical and further clinical research is required before exosome therapy can be considered an established treatment for stroke. (Eun Chae Lee et al., 2022; Hong et al., 2018; Larson et al., 2024; Li et al., 2021)

This paper reviews selected contemporary approaches to stroke treatment, focusing on thrombolysis, mechanical thrombectomy, atorvastatin therapy, VR-based rehabilitation and exosome-based treatment. Together, these approaches illustrate the development of stroke management from acute reperfusion and secondary prevention toward increasingly individualized, technology-assisted and regenerative therapeutic strategies. (Ho & Powers, 2024; Amarenco et al., 2006; Chen et al., 2022; Li et al., 2021)

## **Materials and methods.**

The research method used was a review of the literature on PubMed and Google Scholar using the keywords: “Stroke treatment“. On this basis, it was determined that the treatment methods and guidelines for stroke include: thrombolysis, thrombectomy, atorvastatin, exosomes, VR rehabilitation.

The literature review was then repeated using the phrases: “thrombolysis in stroke treatment“, “thrombectomy in stroke treatment“, “VR rehabilitation in stroke“, “treatment using exosomes in stroke“, “atorvastatin in stroke treatment“. The assessment of the effectiveness of the listed methods was based primarily on systematic reviews, meta-analyses, and randomized controlled trials, which, according to the principles of Evidence-Based Medicine (EBM), constitute scientific evidence of the highest quality and reliability.

## **Results**

### **Treatment using exosomes**

Exosome-based therapy is an emerging approach in stroke treatment that has attracted increasing attention because of its potential neuroprotective and regenerative properties. Exosomes are small extracellular vesicles containing biologically active molecules, including proteins, messenger RNA, and microRNAs, which participate in communication between cells. Their ability to transport these molecules and cross the blood–brain barrier makes them a potential therapeutic tool for neurological disorders, including stroke. (Eun Chae Lee et al., 2022; Hong et al., 2018; Li et al., 2021)

Experimental studies have demonstrated that exosomes derived from mesenchymal stromal cells may contribute to neurological recovery after ischemic stroke. Their effects have been associated with reduced neuronal apoptosis and inflammation, increased angiogenesis and neurogenesis, and enhanced neuroplasticity. These processes may support the restoration of damaged neural tissue and improve functional recovery following cerebral ischemia. (Hong et al., 2018; Li et al., 2021)

The therapeutic effects of exosomes appear to depend partly on their molecular cargo, particularly microRNAs. For example, exosomes enriched in miR-133b or the miR-17–92 cluster have demonstrated beneficial effects on neuronal remodeling and functional recovery in experimental models. Other studies have investigated exosomes containing miR-124 or miR-30d-5p, which may influence neuronal differentiation, inflammatory responses, and cellular survival after ischemic injury. (Hong et al., 2018; Larson et al., 2024; Li et al., 2021)

Exosomes derived from other cell populations, including neural stem cells and adipose-derived stem cells, have also shown therapeutic potential. In experimental models, these vesicles have been associated with reduced infarct volume, preservation of the blood–brain barrier, attenuation of neuroinflammation, and improvement of sensorimotor function. Such findings suggest that the therapeutic effects of exosomes may extend beyond a single molecular pathway and involve several mechanisms of post-stroke tissue repair. (Eun Chae Lee et al., 2022; Larson et al., 2024)

Another promising application is the development of engineered exosomes as targeted delivery systems. Their surface and molecular cargo can be modified to transport specific therapeutic molecules, including microRNAs, proteins, or other bioactive substances, toward damaged brain tissue. This approach may increase treatment specificity and potentially enhance therapeutic efficacy. (Larson et al., 2024; Li et al., 2021)

Despite these promising results, exosome therapy has not yet become an established clinical treatment for stroke. Most available evidence comes from preclinical studies, while clinical research remains limited. Important challenges include determining the optimal dose, administration route and treatment schedule, as

well as developing standardized methods for exosome production, purification, characterization, storage, and quality control. (Eun Chae Lee et al., 2022; Hong et al., 2018; Li et al., 2021)

Overall, exosomes represent a promising experimental strategy for promoting neuroprotection and tissue repair after stroke. Further well-designed clinical studies are necessary to establish their safety, therapeutic efficacy, optimal administration protocols, and potential role in routine stroke management. (Larson et al., 2024; Li et al., 2021)

### **Thrombolysis**

Intravenous thrombolysis is one of the principal reperfusion strategies used in the acute treatment of ischemic stroke. Its primary objective is to restore cerebral blood flow by pharmacologically dissolving the thrombus responsible for arterial occlusion, thereby limiting the progression of ischemic brain injury. (Alonso de Leciñana et al., 2014; Ho & Powers, 2024)

Alteplase, a recombinant form of tissue plasminogen activator (rt-PA), has traditionally been the standard intravenous thrombolytic agent for eligible patients with acute ischemic stroke. Its effectiveness is strongly dependent on rapid administration, with treatment generally recommended within 4.5 hours from symptom onset in appropriately selected patients. (Alonso de Leciñana et al., 2014; Powers et al., 2019)

More recent evidence has increased interest in tenecteplase, a genetically modified tissue plasminogen activator with greater fibrin specificity and a longer plasma half-life than alteplase. These pharmacological properties allow tenecteplase to be administered as a single intravenous bolus, which may simplify treatment delivery and facilitate rapid reperfusion in eligible patients. (Ho & Powers, 2024; De Santis et al., 2026)

The choice of thrombolytic treatment depends on clinical presentation, time from symptom onset, neuroimaging findings, and the presence of contraindications. Recent expert guidance emphasizes that patients with minor ischemic stroke should not be considered automatically unsuitable for thrombolysis; intravenous thrombolysis may be appropriate when the presenting neurological deficit is disabling, even when the overall NIHSS score is low. (De Santis et al., 2026)

Thrombolysis may also be used in selected patients with posterior circulation stroke. Available evidence suggests that intravenous thrombolysis provides benefits comparable to those observed in anterior circulation stroke, while the risk of symptomatic intracranial haemorrhage may be lower in posterior circulation events. (Markus & Michel, 2022)

An important limitation of intravenous thrombolysis is the risk of intracranial haemorrhage, particularly symptomatic intracerebral haemorrhage. Consequently, careful patient selection and urgent neuroimaging are essential before treatment. The benefit of reperfusion is also highly time-dependent, supporting the principle that rapid assessment and treatment are critical in acute ischemic stroke. (Alonso de Leciñana et al., 2014; Ho & Powers, 2024)

Intravenous thrombolysis can be combined with mechanical thrombectomy in patients with large-vessel occlusion who meet the criteria for both treatments. Current evidence supports avoiding unnecessary delays to endovascular treatment while administering intravenous thrombolysis to eligible patients within the appropriate therapeutic window. (Zi et al., 2021; Powers et al., 2019)

Overall, thrombolysis remains an important component of acute ischemic stroke management. The development of tenecteplase and improved patient-selection strategies may further expand and optimize pharmacological reperfusion therapy, although treatment decisions should remain individualized and based on current clinical evidence and eligibility criteria. (Ho & Powers, 2024; De Santis et al., 2026)

### **Thrombectomy**

Mechanical thrombectomy is an established reperfusion therapy for selected patients with acute ischemic stroke caused by occlusion of a major intracranial artery. The procedure involves endovascular navigation to the site of arterial obstruction, followed by mechanical removal of the thrombus, with the aim of rapidly restoring cerebral blood flow and limiting irreversible brain injury. (Ho & Powers, 2024; De Santis et al., 2026)

Patient selection for thrombectomy is primarily based on clinical assessment and neuroimaging. Computed tomography or magnetic resonance imaging is used to assess the extent of established infarction, while vascular imaging, particularly CT angiography, is used to identify large-vessel occlusion. In selected cases, additional perfusion imaging can help determine whether potentially salvageable brain tissue remains. (Ho & Powers, 2024; Alonso de Leciñana et al., 2014)

The effectiveness of thrombectomy is strongly influenced by the time from symptom onset to reperfusion. Current evidence supports treatment within the early therapeutic window and, in appropriately selected patients, during an extended window of up to 24 hours after the patient was last known to be well. Advanced imaging and clinical criteria can identify patients who may still benefit from endovascular treatment despite delayed presentation. (Ho & Powers, 2024; De Santis et al., 2026)

Mechanical thrombectomy has also been investigated in patients presenting with large established ischemic infarctions. Recent randomized trials have provided evidence supporting endovascular treatment in selected patients with large infarct cores, suggesting that the potential benefits of thrombectomy may extend beyond the patient populations included in the earlier landmark trials. (Ho & Powers, 2024)

Thrombectomy may be performed in conjunction with intravenous thrombolysis in eligible patients. When a patient meets the criteria for intravenous thrombolysis and has a large-vessel occlusion requiring endovascular treatment, thrombolysis should generally not be delayed while preparations for thrombectomy are undertaken. This combined approach is commonly referred to as bridging therapy. (Ho & Powers, 2024; Zi et al., 2021)

The relationship between intravenous thrombolysis and thrombectomy has been investigated in randomized clinical trials. Evidence from the DEVT trial indicated that endovascular treatment alone was non-inferior to intravenous alteplase followed by endovascular treatment in a selected population with large-vessel occlusion, although these findings do not imply that intravenous thrombolysis should routinely be omitted in all eligible patients. (Zi et al., 2021)

Thrombectomy has also been evaluated in posterior circulation stroke, particularly in patients with basilar artery occlusion. Recent trials have expanded the evidence base for endovascular treatment in this population, although patient selection and the balance between potential benefit and procedural risk remain important considerations. (Ho & Powers, 2024)

Overall, mechanical thrombectomy represents a major advance in the treatment of acute ischemic stroke. Its effectiveness is closely related to rapid diagnosis, appropriate neuroimaging, accurate identification of arterial occlusion, and timely reperfusion. Ongoing research continues to define the optimal selection criteria and the populations that may benefit from thrombectomy, particularly those presenting with delayed treatment or extensive established infarction. (Ho & Powers, 2024; De Santis et al., 2026)

### **Treatment using atorvastatin**

Atorvastatin is a high-intensity statin that plays an important role in the secondary prevention of vascular events after ischemic stroke or transient ischemic attack (TIA). Its primary pharmacological effect is the reduction of low-density lipoprotein cholesterol (LDL-C), which contributes to a lower risk of recurrent cerebrovascular and cardiovascular events. (Amarenco et al., 2006; Hulsa et al., 2010)

The clinical efficacy of high-dose atorvastatin was demonstrated in the SPARCL trial, which included 4,731 patients with a recent stroke or TIA and no known coronary heart disease. Participants received either 80 mg of atorvastatin daily or placebo and were followed for a median of 4.9 years. Atorvastatin treatment was associated with a lower incidence of fatal or non-fatal stroke compared with placebo, with an adjusted hazard ratio of 0.84 and a 2.2% absolute reduction in five-year stroke risk. (Amarenco et al., 2006)

The SPARCL trial also demonstrated a reduction in major cardiovascular events among patients receiving high-dose atorvastatin. These findings support the use of intensive statin therapy as an important component of secondary vascular prevention following ischemic stroke or TIA. (Amarenco et al., 2006; Hulsa et al., 2010)

In addition to its lipid-lowering action, atorvastatin may exert several pleiotropic effects that could be relevant to cerebral ischemia. Experimental and translational research suggests that statins may influence inflammatory and oxidative pathways and may contribute to neuroprotection independently of their effects on cholesterol levels. (Hulsa et al., 2010; L. Chen et al., 2025)

Recent experimental research has investigated the potential anti-inflammatory effects of atorvastatin through the gut-brain axis. In an ischemic stroke model, atorvastatin was associated with reduced microglial activation and inhibition of inflammatory pathways involving NF- $\kappa$ B and the NLRP3 inflammasome. Changes in specific gut bacterial populations were also associated with better neurological outcomes, suggesting that modulation of the gut microbiota may contribute to some of the drug's effects. (L. Chen et al., 2025)

Further evidence from an experimental rat model indicated that atorvastatin reduced the expression of TLR4 and NF- $\kappa$ B in brain tissue and was associated with an improvement in neurological deficit scores. These findings support a possible role for atorvastatin in reducing neuroinflammation and protecting cerebral tissue

after ischemic injury, although such mechanisms require further confirmation in clinical studies. (Wang et al., 2020)

Despite its established role in secondary prevention, the use of high-dose atorvastatin requires consideration of the individual risk–benefit profile. The SPARCL trial reported a small increase in hemorrhagic stroke in the atorvastatin group, although the overall incidence was low and the reduction in ischemic and cardiovascular events supported the net clinical benefit of treatment in the studied population. (Amarenco et al., 2006; Hulsa et al., 2010)

Overall, atorvastatin represents an established component of secondary prevention after ischemic stroke or TIA. Its benefits are primarily related to intensive lipid lowering and reduction of recurrent vascular events, while emerging evidence suggests additional anti-inflammatory and neuroprotective mechanisms that may contribute to recovery following cerebral ischemia. (Amarenco et al., 2006; L. Chen et al., 2025)

### **Rehabilitation using VR technology**

Virtual reality (VR) has emerged as a promising technology-assisted approach in post-stroke rehabilitation. It enables patients to perform repetitive and task-oriented exercises within interactive virtual environments, potentially increasing motivation and engagement during rehabilitation. VR can be implemented as an adjunct to conventional physiotherapy rather than as a replacement for established rehabilitation methods. (Peláez-Vélez et al., 2023; Chen et al., 2022)

One of the main applications of VR in stroke rehabilitation is the improvement of upper-limb motor function. Systematic reviews and meta-analyses have reported beneficial effects of VR-supported exercise on upper-extremity motor performance, particularly when VR is incorporated into conventional rehabilitation programmes. The repetitive and interactive nature of VR exercises may facilitate motor learning and promote active participation during therapy. (Chen et al., 2022; Wu et al., 2021; Soleimani et al., 2024)

VR-based rehabilitation may also improve balance and functional mobility. Evidence from systematic reviews indicates positive effects on balance-related outcomes, while clinical studies have reported improvements in gait, trunk control and functional ambulation following combined conventional physiotherapy and VR interventions. (Wu et al., 2021; Peláez-Vélez et al., 2023)

The potential benefits of VR are partly related to its ability to provide repetitive, goal-oriented and progressively adjustable exercises. Virtual tasks can be adapted to the individual patient's abilities, allowing the intensity and difficulty of training to be modified during rehabilitation. Such characteristics may increase treatment adherence and provide patients with immediate visual or interactive feedback regarding their performance. (Peláez-Vélez et al., 2023; Chen et al., 2022)

A pilot randomized controlled trial involving patients in the post-stroke recovery period found that adding VR-based exercises to conventional neurological physiotherapy resulted in significant improvements in motor function, trunk control, balance and functional gait compared with physiotherapy alone. However, no significant between-group differences were observed for muscle strength or spasticity, indicating that the effects of VR may vary according to the rehabilitation outcome assessed. (Peláez-Vélez et al., 2023)

The effectiveness of VR may also depend on the type of technology and rehabilitation protocol used. Immersive systems using head-mounted displays provide a high degree of interaction with the virtual environment, whereas non-immersive systems may be easier to implement and better tolerated by some patients. Differences in intervention duration, training intensity, technological systems and patient characteristics may contribute to variability between studies. (Peláez-Vélez et al., 2023; Soleimani et al., 2024)

Despite encouraging findings, several limitations should be considered. The available studies differ substantially in terms of intervention protocols, outcome measures, technology and patient populations, while some trials have relatively small sample sizes. Consequently, further high-quality randomized controlled trials are required to establish optimal VR protocols and determine which patients are most likely to benefit from this approach. (Chen et al., 2022; Wu et al., 2021; Soleimani et al., 2024)

Overall, VR represents a promising adjunctive strategy in post-stroke rehabilitation, particularly for improving upper-limb function, balance and aspects of functional mobility. Its integration with conventional physiotherapy may enhance the intensity and engagement of rehabilitation, although further research is needed to determine the most effective technologies, treatment parameters and patient-specific applications. (Peláez-Vélez et al., 2023; Soleimani et al., 2024)

## Discussion

The reviewed evidence demonstrates that stroke treatment requires a multimodal approach combining acute reperfusion, secondary prevention and rehabilitation. Thrombolysis and mechanical thrombectomy remain the most established strategies for restoring cerebral blood flow in appropriately selected patients, with treatment effectiveness strongly influenced by rapid diagnosis and timely intervention.

Atorvastatin plays an important role in secondary prevention by reducing the risk of recurrent stroke and other cardiovascular events. In addition to its lipid-lowering effects, emerging evidence suggests potential anti-inflammatory and neuroprotective properties, although these mechanisms require further clinical investigation.

Rehabilitation is essential for improving functional recovery after stroke. VR-based rehabilitation may complement conventional therapy by increasing repetition, patient engagement and task-oriented training. However, differences between VR systems, treatment protocols and patient populations make it difficult to determine the optimal rehabilitation strategy.

Exosome-based therapy represents a promising area of regenerative medicine. Preclinical studies suggest potential neuroprotective, anti-inflammatory and neuroregenerative effects, but clinical evidence remains limited. Therefore, exosomes should currently be considered an experimental treatment rather than an established component of stroke management.

Overall, combining established therapies with emerging approaches may contribute to more individualized stroke care. Further high-quality clinical studies are needed to determine the long-term effectiveness, safety and appropriate application of newer therapeutic strategies.

## Conclusions

Stroke treatment requires a comprehensive approach combining acute management, secondary prevention and rehabilitation. Thrombolysis and mechanical thrombectomy remain key interventions for restoring cerebral blood flow in appropriately selected patients, with early diagnosis and rapid treatment being essential for optimal outcomes.

Atorvastatin plays an important role in secondary prevention by reducing the risk of recurrent vascular events, while its potential anti-inflammatory and neuroprotective effects may provide additional benefits. VR-based rehabilitation represents a promising complementary method that may support motor recovery, balance and functional independence.

Exosome-based therapy offers potential for neuroprotection and neural regeneration, but current evidence remains mainly preclinical. Further clinical research is therefore necessary to establish its safety and effectiveness.

Overall, combining established treatments with innovative therapeutic approaches may contribute to more individualized and effective stroke care and improve long-term patient outcomes.

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