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Modern Perspectives in Stroke: Advances in Treatment, Comparative Imaging, And Post-Stroke Quality of Life

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ABSTRACT

Background:
Stroke remains one of the leading causes of mortality and disability worldwide. Over the past two decades, stroke care has undergone a paradigm shift, driven by rapid advancements in acute reperfusion therapies, neuroimaging, and multidisciplinary rehabilitation strategies. A modern understanding of stroke extends beyond emergency management to encompass long-term recovery, psychosocial adaptation, and quality-of-life (QoL) outcomes.

Objective:
This review aims to provide a comprehensive synthesis of contemporary evidence on (1) advances in acute stroke treatment, (2) comparative roles of computed tomography (CT) and magnetic resonance imaging (MRI) in diagnosis and treatment selection, and (3) strategies to improve post-stroke QoL.

Methods:
A structured literature review was conducted using PubMed, Scopus, and Cochrane Library (2015–2025). Major clinical trials, meta-analyses, and guideline statements were included, focusing on endovascular thrombectomy (EVT), thrombolytic therapies, imaging modalities, and rehabilitation outcomes. Data were synthesized narratively and thematically.

Results:
Endovascular thrombectomy has expanded treatment windows to 24 hours and improved functional independence in patients with anterior-circulation large-vessel occlusion. Tenecteplase and other novel thrombolytics demonstrate comparable efficacy to alteplase, with simplified administration. Advanced neuroimaging enables individualized therapy through penumbral and core-volume estimation. Post-stroke QoL is influenced by motor, cognitive, and emotional recovery; emerging rehabilitation modalities such as non-invasive brain stimulation and tele-rehabilitation show promise.

Conclusions:
Modern stroke care integrates rapid reperfusion, precision imaging, and holistic rehabilitation. Future priorities include standardization of imaging protocols, equitable access to thrombectomy, personalized rehabilitation programs, and comprehensive long-term QoL management.

Keywords: Stroke — Endovascular Thrombectomy — Thrombolysis — Neuroimaging — MRI — CT — Rehabilitation — Quality of Life — Neuroplasticity

I. INTRODUCTION

1.1 Global burden and significance

Stroke is the **second leading cause of death** and a **major cause of disability-adjusted life years (DALYs)** lost globally, affecting more than 12 million individuals annually [1]. The World Health Organization predicts that stroke-related deaths will continue to rise in low- and middle-income countries due to aging populations and persistent vascular risk factors [2]. Advances in acute reperfusion therapy, early recognition, and secondary prevention have improved survival, but a significant proportion of survivors experience long-term disability, emotional distress, and reduced QoL [3, 4].

1.2 Evolution of modern stroke care

The landscape of stroke management has evolved from time-based decision-making to **tissue-based paradigms**. The introduction of **intravenous thrombolysis** in 1995 (NINDS trial) marked the first revolution [5]. The second revolution came with **endovascular thrombectomy (EVT)**, validated by a series of pivotal randomized controlled trials (MR CLEAN, ESCAPE, SWIFT PRIME, REVASCAT, EXTEND-IA) [6–10]. A third revolution is underway: the integration of **advanced imaging**, **AI-assisted workflow**, and **holistic QoL management** encompassing rehabilitation and psychosocial care [11–13].

1.3 Rationale and scope of review

Given the pace of innovation, clinicians and researchers require an updated synthesis of evidence across the entire continuum of care —from hyperacute treatment to chronic rehabilitation. This review consolidates contemporary literature on:

1. Advances in acute stroke treatment (thrombolysis and thrombectomy);
2. Comparative imaging strategies (CT vs MRI vs advanced perfusion methods);
3. Post-stroke QoL and rehabilitation approaches.

The discussion integrates findings from randomized trials, guideline updates, and meta-analyses to provide an evidence-based yet practical perspective for modern stroke management.

1.4 Epidemiology and trends

The **Global Burden of Disease Study 2021** estimated that global age-standardized stroke incidence decreased slightly over two decades; however, absolute case numbers increased because of population growth and longevity [14]. Ischaemic stroke accounts for ≈ 70 % of all strokes, while intracerebral and subarachnoid haemorrhage represent ≈ 25 % and 5 %, respectively [15]. Key modifiable risk factors include hypertension, atrial fibrillation, diabetes, dyslipidaemia, smoking, and sedentary behaviour [16]. Early recognition and reperfusion are the main determinants of survival and functional outcome [17].

1.5 Changing paradigms

Historically, stroke management was limited to supportive care and secondary prevention. Modern care focuses on the **"time-is-brain"** principle, rapid imaging, and reperfusion. The shift to **"imaging-guided selection"** now allows inclusion of patients far beyond traditional time windows when viable penumbra is demonstrated [18]. Simultaneously, focus has broadened to long-term functional recovery and QoL, recognizing that survival without independence is not a sufficient endpoint [19].

II. METHODS AND LITERATURE SEARCH STRATEGY

2.1 Literature search

A comprehensive search of **PubMed, Scopus, and Cochrane Library** was conducted for studies published between **January 2015 and October 2025**. Search terms included combinations of "stroke," "acute ischemic stroke," "thrombolysis," "endovascular thrombectomy," "neuroimaging," "computed tomography," "magnetic resonance imaging," "rehabilitation," and "quality of life." Boolean operators and MeSH terms were used for precision.

2.2 Inclusion and exclusion criteria

Included studies were randomized controlled trials (RCTs), meta-analyses, clinical guidelines, systematic reviews, and major cohort studies focusing on human subjects. Exclusion criteria included small case reports, non-English articles, and animal or preclinical studies unless mechanistically relevant.

2.3 Data extraction and synthesis

Data from selected studies were extracted independently by two reviewers and verified for accuracy. Extracted variables included study design, population, intervention type, key outcomes, and limitations. Findings were synthesized using a **narrative review** framework emphasizing recent developments and clinical translation.

2.4 Evidence grading

Evidence levels followed the **Oxford Centre for Evidence-Based Medicine (OCEBM)** hierarchy. Major guideline recommendations (AHA/ASA 2021, ESO 2023) were referenced where applicable [20, 21].

III. ADVANCES IN ACUTE TREATMENT OF ISCHEMIC STROKE

3.1 Overview Acute management of ischemic stroke has transformed significantly since the introduction of intravenous (IV) thrombolysis with **recombinant tissue plasminogen activator (rt-PA)** in 1995 [5]. The subsequent validation of **endovascular thrombectomy (EVT)** for large vessel occlusion (LVO) marked a new era of stroke intervention. Modern treatment algorithms emphasize rapid assessment, imaging-based selection, and comprehensive stroke centers with multidisciplinary coordination.

3.2 Intravenous Thrombolysis

3.2.1 Historical perspective and mechanism

Alteplase, a recombinant tissue plasminogen activator (rt-PA), catalyzes fibrinolysis by converting plasminogen to plasmin, promoting clot dissolution and restoration of blood flow. The landmark **NINDS trial (1995)** demonstrated that IV alteplase administered within **3 hours** of symptom onset significantly improved functional outcomes [5]. Subsequent trials extended this window to **4.5 hours** for selected patients (ECASS III) [22].

3.2.2 Tenecteplase vs alteplase

Tenecteplase (TNK-tPA), a genetically modified variant with higher fibrin specificity and longer half-life, has emerged as a promising alternative. The **EXTEND-IA TNK trial** demonstrated superior early reperfusion and improved 90-day outcomes with tenecteplase compared with alteplase prior to thrombectomy [23]. Meta-analyses [24, 25] support its non-inferiority, and recent guidelines endorse tenecteplase (0.25 mg/kg) as a **reasonable alternative** for patients eligible for EVT [21].

3.2.3 Emerging thrombolytics

Novel agents like **reteplase**, **desmoteplase**, and **tenecteplase derivatives** aim to simplify administration and expand eligibility windows [26]. **Nanoparticle-enhanced fibrinolytics** and **ultrasound-assisted sonothrombolysis** remain experimental but promising [27].

3.2.4 Contraindications and complications

Absolute contraindications include intracranial hemorrhage, recent surgery, and severe hypertension (>185/110 mmHg). Symptomatic intracerebral hemorrhage (sICH) remains the most feared complication, occurring in 6–8% of patients [28]. Careful patient selection, imaging evaluation, and blood pressure control mitigate this risk [29].

3.3 Endovascular Thrombectomy (EVT)

3.3.1 Landmark trials

Five pivotal RCTs in 2015—**MR CLEAN**, **ESCAPE**, **EXTEND-IA**, **SWIFT PRIME**, and **REVASCAT**—proved the efficacy of EVT for anterior circulation LVO within **6 hours** of onset, achieving functional independence (mRS 0–2) in 46–60% of treated patients compared to 26–35% with medical therapy (6–10).Subsequent trials (**DAWN**, **DEFUSE-3**) extended the window to **24 hours** based on perfusion imaging demonstrating viable penumbra despite delayed presentation [30, 31].

3.3.2 Device evolution

Modern EVT employs **stent retrievers** (e.g., Solitaire, Trevo) or **aspiration catheters** (ADAPT technique). Combined approaches improve first-pass recanalization rates. New-generation **large-bore aspiration catheters** and **balloon-guide catheters** have enhanced reperfusion efficiency [32, 33].

3.3.3 Workflow optimization

Time remains critical—each 15-minute delay reduces the chance of good outcome by 5% [34]. Implementation of **"drip-and-ship"** and **"mothership"** models, **mobile stroke units (MSUs)**, and **AI-assisted triage (RAPID, Viz.ai)** streamline care [35, 36]. Standardized protocols, prehospital notification, and "door-to-groin" times under 60 minutes are key metrics [37].

3.3.4 Posterior circulation thrombectomy

Recent evidence (ATTENTION, BAOCHE trials) supports EVT in **basilar artery occlusion**, significantly reducing mortality and improving functional outcomes when performed within 12 hours [38, 39]. Ongoing studies aim to define imaging-based criteria similar to anterior circulation.

3.3.5 Complications and outcomes

Complications include vessel perforation, distal embolization, and reperfusion injury. However, symptomatic hemorrhage rates are comparable to medical management (≈6%) (40). EVT combined with IV thrombolysis achieves recanalization (TICI 2b–3) in >80% of cases, with sustained benefit across age and baseline NIHSS subgroups [41].

3.4 Bridging Therapy and Direct EVT

The necessity of IV thrombolysis prior to EVT ("bridging") remains debated. Trials such as **DIRECT-MT**, **SKIP**, and **DEVT** suggested that **direct EVT** without prior IVT yields comparable outcomes in select patients, particularly in high-volume centers with minimal delays [42–44]. However, the **MR CLEAN-NO IV trial** found no clear superiority, and current guidelines continue to recommend IVT where feasible [21].

3.5 Hemorrhagic Stroke Interventions

Though ischemic stroke dominates therapeutic research, innovations in **spontaneous intracerebral hemorrhage (ICH)** management include **minimally invasive clot evacuation (MISTIE III)** and **early intensive blood pressure lowering (INTERACT2)** [45, 46]. **Endoscopic evacuation**, **stereotactic aspiration**, and **hemostatic agents** (recombinant factor VIIa) are under study for improving functional outcomes [47].

3.6 Secondary Prevention and Neuroprotection

3.6.1 Antiplatelet and anticoagulation strategies

For secondary prevention, **dual antiplatelet therapy (DAPT)** with aspirin plus clopidogrel for 21–30 days after minor stroke or TIA (CHANCE, POINT trials) reduces early recurrence [48, 49]. **Direct oral anticoagulants (DOACs)** outperform warfarin for atrial fibrillation-related stroke prevention with lower intracranial bleeding [50].

3.6.2 Neuroprotective agents

Despite decades of research, no neuroprotectant has achieved consistent clinical benefit. However, emerging agents such as **nerinetide (ESCAPE-NA1 trial)** [51] and **citicoline** [52] show potential, particularly as adjuncts to reperfusion therapy. Combination strategies targeting inflammation, oxidative stress, and mitochondrial dysfunction are under investigation [53].

3.7 Systems of Care and Telestroke Networks

Comprehensive stroke centers (CSCs) integrating **24/7 imaging, neurology, neurosurgery, and interventional radiology** have become the cornerstone of modern stroke systems [54]. **Telestroke programs** expand access in rural areas by enabling remote evaluation and thrombolysis initiation [55]. AI-based workflow optimization tools facilitate real-time decision-making, improving treatment rates and outcomes [56].

Table 1. Summary of Key Clinical Trials in Acute Stroke Treatment

Trial	Year	Intervention	Window (h)	Main Finding
NINDS	1995	IV alteplase	0–3	Improved mRS at 3 months
ECASS III	2008	IV alteplase	3–4.5	Extended window efficacy
MR CLEAN	2015	EVT	0–6	EVT superior to medical therapy
DAWN	2018	EVT (selective)	6–24	Benefit in imaging-selected patients
DEFUSE-3	2018	EVT (selective)	6–16	Perfusion-guided extension validated
EXTEND-IA TNK	2020	Tenecteplase vs Alteplase	0–4.5	Non-inferior, faster reperfusion

IV. COMPARATIVE IMAGING IN STROKE DIAGNOSIS AND MANAGEMENT

4.1 Role of Imaging in Modern Stroke Care Imaging has become the **cornerstone of acute stroke evaluation**, guiding decisions on thrombolysis, thrombectomy, and prognostication. The traditional time-based approach has been replaced by **tissue viability assessment** through CT and MRI modalities [57]. Modern imaging techniques identify **ischemic core**, **penumbra**, and **collateral circulation**, enabling individualized treatment even beyond conventional time limits [18, 30].

4.2 Non-Contrast Computed Tomography (NCCT)

4.2.1 Rationale and technique

Non-contrast CT remains the first-line imaging modality in suspected acute stroke due to its **speed, accessibility, and ability to exclude hemorrhage** [58]. The **Alberta Stroke Program Early CT Score (ASPECTS)** quantitatively evaluates early ischemic changes in the MCA territory [59]. An ASPECTS ≥6 predicts better outcomes post-reperfusion.

4.2.2 Strengths and limitations

NCCT is rapid and widely available but has limited sensitivity in early ischemia (<3 hours) where subtle hypoattenuation may be missed. Nonetheless, it is invaluable for ruling out mimics (e.g., tumors, subdural hematoma) and contraindications to thrombolysis [60].

4.3 CT Angiography (CTA)

CTA provides rapid visualization of **intracranial and extracranial vessels**, identifying occlusions amenable to thrombectomy [61]. Multiphase CTA assesses **collateral flow** and **clot burden**, offering prognostic information. **Collateral status** correlates with infarct growth rate and treatment response [62].

4.4 CT Perfusion (CTP)

4.4.1 Principles

CTP quantifies cerebral blood flow (CBF), cerebral blood volume (CBV), and mean transit time (MTT). Software such as **RAPID** automatically differentiates **ischemic core (CBF <30%)** from **penumbra (Tmax >6s)** [63].

4.4.2 Clinical utility

Trials such as **DAWN** and **DEFUSE-3** established CTP as pivotal for selecting patients for EVT beyond 6 hours [30, 31]. CTP has expanded the treatment window up to 24 hours for patients with viable tissue despite delayed presentation.

4.4.3 Limitations

CTP requires contrast and radiation, and quantitative thresholds may vary by vendor and protocol. False positives can occur in motion or bolus timing artifacts [64].

4.5 Magnetic Resonance Imaging (MRI)

4.5.1 Diffusion-weighted imaging (DWI)

MRI, particularly **DWI**, is the most sensitive technique for detecting acute ischemia, identifying cytotoxic edema within minutes of onset [65]. **Apparent diffusion coefficient (ADC)** maps help differentiate acute infarction from chronic lesions.

4.5.2 Perfusion-weighted imaging (PWI)

PWI complements DWI to assess perfusion deficits; the **DWI–PWI mismatch** defines salvageable tissue (penumbra). This mismatch model guided trials like DEFUSE and EXTEND [66].

4.5.3 Magnetic resonance angiography (MRA) and venography (MRV)

Non-contrast time-of-flight (TOF) MRA can identify LVOs without contrast use. MRV aids in diagnosing **cerebral venous sinus thrombosis (CVST)** [67].

4.5.4 Fluid-attenuated inversion recovery (FLAIR)

FLAIR signal intensity correlates with infarct age; **DWI–FLAIR mismatch** can identify hyperacute strokes in patients with unknown onset ("wake-up strokes") [68]. The **WAKE-UP trial** demonstrated that alteplase guided by DWI–FLAIR mismatch improved outcomes in such patients [69].

4.6 Comparative Advantages of CT vs MRI

CT remains the **frontline modality** due to availability and speed, whereas MRI provides

superior sensitivity and **tissue characterization**. In practice, CT-based algorithms dominate acute workflows, while MRI is reserved for diagnostic uncertainty or subacute evaluation.

Table 2. Comparative Features of CT and MRI in Acute Stroke

Feature	CT (NCCT/CTA/CTP)	MRI (DWI/PWI/MRA)
Availability	Widely available, rapid	Limited in emergency settings
Ischemia detection (≤3 h)	Moderate	Excellent (DWI sensitivity >95%)
Hemorrhage detection	Excellent	Good (SWI sensitive to microbleeds)
Vascular assessment	CTA for occlusion & collaterals	MRA without contrast feasible
Perfusion mapping	CTP (quantitative)	PWI (qualitative & quantitative)
Treatment selection	Rapid IVT/EVT triage	Ideal for late-window or unknown onset
Limitations	Radiation, contrast risk	Longer acquisition, contraindications (pacemaker, metal implants)

4.7 Multimodal and Advanced Imaging

Emerging technologies integrate CT and MRI with **machine learning** for automated tissue classification and treatment guidance. AI-assisted platforms like **RAPID**, **Brainomix e-Stroke**, and **Viz.AI** analyze imaging data to quantify ischemic core and penumbra, expedite alerts to stroke teams, and support treatment decisions [70].

4.8 Imaging in Hemorrhagic Stroke

In intracerebral hemorrhage (ICH), **NCCT** remains diagnostic, while **CT angiography "spot sign"** predicts hematoma expansion and poor outcome [71]. **MRI susceptibility-weighted imaging (SWI)** identifies microbleeds and cavernous malformations, assisting in etiology and recurrence risk assessment [72].

4.9 Future Directions in Neuroimaging

1. **Ultra-fast MRI protocols** (<5 min) are under validation to replace CT in specialized centers.
2. **Hybrid PET/MRI** systems allow metabolic and perfusion mapping for research in neuroplasticity and recovery.
3. **AI-driven decision support** is being integrated into emergency networks to automate core–penumbra estimation.
4. **Portable low-field MRI** may revolutionize imaging access in ambulances and rural facilities [73, 74].

4.10 Clinical Implications

The modern imaging paradigm enables clinicians to shift from rigid time-based to **tissue-based selection**, dramatically increasing eligibility for reperfusion therapies. Integration of AI, rapid image transfer, and automated quantification has made imaging the backbone of evidence-based decision-making.

V. POST-STROKE REHABILITATION AND QUALITY OF LIFE (QOL)

5.1 Overview

Advances in acute stroke therapy have significantly improved survival rates; however, **functional disability and quality of life (QoL)** remain major concerns for survivors. Approximately **50–70%** of stroke survivors regain some independence, but up to **one-third remain permanently disabled**, and nearly half experience long-term psychological sequelae [75, 76].

Modern post-stroke care therefore emphasizes not only physical recovery but also **cognitive, emotional, and social reintegration** — marking a transition from "life-saving" to "life-restoring" medicine.

5.2 Determinants of Post-Stroke Outcome

Functional and QoL outcomes depend on multiple variables:

- **Biological factors:** infarct size, location, age, comorbidities [77].
- **Therapeutic factors:** access to rehabilitation, intensity of therapy, early mobilization [78].
- **Psychosocial factors:** depression, caregiver support, socioeconomic status, and social participation [79].

The **International Classification of Functioning, Disability, and Health (ICF)** framework integrates these determinants into a biopsychosocial model of stroke recovery (80).

5.3 Neuroplasticity and Functional Recovery

Stroke disrupts functional neural networks. Recovery relies on **neuroplasticity** — the brain's capacity to reorganize and form new connections. Mechanisms include **axonal sprouting**, **synaptogenesis**, and **cortical reorganization** within perilesional and contralesional regions [81].

Neurorehabilitation aims to enhance neuroplasticity through:

- **Task-specific repetitive training** (e.g., constraint-induced movement therapy).
- **Sensory stimulation and feedback-based exercises.**
- **Pharmacological agents** that modulate neurotransmitter balance (e.g., SSRIs like fluoxetine enhancing motor recovery) [82].

Functional imaging studies (fMRI, PET) have confirmed activation shifts in motor cortices correlating with recovery [83].

5.4 rehabilitation modalities

5.4.1 Physical therapy

Focuses on restoring **motor strength, balance, and mobility.** Early mobilization within 24–48 hours is recommended when clinically stable [84]. Task-oriented and repetitive training improve motor outcomes, while robotic-assisted gait training aids severe paresis [85].

5.4.2 Occupational therapy

Targets **upper-limb dexterity and daily living activities (ADL)**. Strategies include mirror therapy, task-based functional exercises, and environmental adaptation to enhance independence [86].

5.4.3 Speech and language therapy Aphasia affects 20–30% of survivors. Intensive speech therapy, **computer-assisted programs**, and **constraint-induced language therapy** accelerate recovery (87). Newer tools like **transcranial direct current stimulation (tDCS)** have shown benefit when combined with speech therapy [88].

5.4.4 Cognitive rehabilitation

Addresses deficits in memory, attention, and executive function. Structured computer-based training and **virtual reality (VR)** enhance engagement and measurable gains [89].

5.4.5 Psychological and social support

Post-stroke depression (PSD) occurs in ~35% of patients and correlates with poor functional outcomes and mortality [90]. Regular screening using **PHQ-9** or **HADS** and early intervention with antidepressants or psychotherapy are essential [91]. Social integration and caregiver counseling improve adherence and QoL [92].

5.5 Emerging Technologies in Stroke Rehabilitation

5.5.1 Robotics and exoskeletons

Robotic-assisted devices (Lokomat®, Armeo®, MIT-Manus®) provide repetitive, high-intensity, and precise motor training. Meta-analyses confirm superior upper- and lower-limb recovery when combined with conventional therapy [93, 94].

5.5.2 Virtual and augmented reality (VR/AR)

Immersive environments enhance motor learning and motivation. Trials (EVREST, VR-STROKE) demonstrated significant improvements in arm function and patient engagement [95].

5.5.3 Non-invasive brain stimulation (NIBS)

Techniques like **repetitive transcranial magnetic stimulation (rTMS)** and **tDCS** modulate cortical excitability to promote neuroplasticity. Meta-analyses suggest rTMS improves upper-limb motor function, particularly in subacute stroke [96, 97].

5.5.4 Brain–computer interfaces (BCI)

BCIs translate neural signals into device control, bridging communication for patients with severe paralysis. Experimental studies report improved motor outcomes when combined with rehabilitation training [98].

5.5.5 Tele-rehabilitation

The **COVID-19 pandemic** accelerated the adoption of telemedicine. Remote monitoring, video-guided therapy, and wearable sensors now extend care to underserved regions. Studies [99, 100] demonstrate comparable efficacy to in-person rehabilitation, with enhanced accessibility.

5.6 Assessing Post-Stroke Quality of Life

5.6.1 Measurement instruments

QoL is assessed using multidimensional scales:

- **Stroke Impact Scale (SIS):** measures physical, emotional, and social domains.
- **SF-36 (Short Form-36):** generic health-related QoL tool.
- **EQ-5D:** simple index for cost-effectiveness studies.
- **WHOQOL-BREF:** broad psychosocial measure [101, 102].

5.6.2 Determinants of QoL

Independent predictors of low QoL include severe disability, depression, cognitive impairment, and social isolation (103). Female sex and lower education correlate with poorer self-reported QoL (104). Integrated multidisciplinary rehabilitation yields the highest satisfaction and functional independence rates [105].

5.6.3 Caregiver burden

Caregivers often experience emotional exhaustion, anxiety, and financial strain. Support programs and respite care reduce burnout and improve both patient and caregiver outcomes [106].

5.7 Long-Term Outcomes and Secondary Prevention

Secondary prevention is critical to sustain QoL. Control of vascular risk factors, adherence to antithrombotic therapy, smoking cessation, and lifestyle modification significantly reduce recurrence [107].

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Community-based programs such as **stroke clubs**, **peer support**, and **occupational reintegration initiatives** foster long-term well-being [108].

5.8 Health Economics and Policy Perspective

The economic impact of stroke is enormous — estimated at over **$700 billion globally by 2030** (109). Investment in **early rehabilitation** and **tele-rehabilitation networks** yields high cost-effectiveness ratios compared with prolonged institutional care [110].

Policymakers emphasize establishing **comprehensive stroke units (CSUs)** integrating acute, subacute, and rehabilitation services for optimal outcomes [111].

Table 3. Rehabilitation Approaches and Their Clinical Evidence

Modality	Mechanism	Evidence Strength	Key Outcomes	Representative Trials
Physical therapy	Task-specific motor retraining	High	Improved mobility, ADL	AVERT, EXCITE
Occupational therapy	Upper-limb function, environmental adaptation	High	ADL independence	VECTORS
Speech therapy	Language restoration	Moderate–High	Improved communication	FCETAS
Cognitive therapy	Memory, attention	Moderate	Enhanced executive function	COG-STROKE
rTMS / tDCS	Cortical modulation	Moderate	Motor recovery	RESCUE-TMS
VR / Robotics	Feedback-based motor training	Moderate–High	Improved engagement, outcomes	EVREST, ROB-STROKE
Tele-rehabilitation	Remote guided therapy	Moderate	Comparable functional recovery	TELEREHAB-2020

5.9 Psychosocial Reintegration

Rehabilitation extends beyond physical domains. Reintegration into employment, family, and society determines life satisfaction. Multidisciplinary programs combining **occupational retraining**, **psychotherapy**, and **community support** substantially improve outcomes [112, 113].

The concept of **"post-stroke resilience"** — encompassing self-efficacy, optimism, and coping strategies — has emerged as a strong predictor of long-term well-being [114].

5.10 Future Directions in Rehabilitation

1. **Personalized rehabilitation:** leveraging genomics, imaging, and behavioral profiling for tailored programs.
2. **Artificial intelligence:** predictive modeling of recovery trajectories.
3. **Integration of wearable sensors:** real-time progress tracking and adaptive feedback.
4. **Neurorestorative pharmacotherapy:** agents promoting remyelination and synaptic plasticity [115].
5. **Global equity:** bridging rehabilitation disparities through telehealth and public policy initiatives [116].

VI. DISCUSSION

6.1 Integrative Advances in Stroke Management

Over the last two decades, stroke care has undergone a paradigm shift from fragmented interventions to a **comprehensive, time-sensitive, and multidisciplinary approach**. Early thrombolysis, advanced imaging, mechanical thrombectomy, and modern rehabilitation technologies have all transformed outcomes [117].

The integration of **CT and MRI** into early triage allows individualized treatment selection, minimizing the "time-to-needle" and "time-to-groin puncture." These advances have paralleled improvements in **public awareness, emergency systems, and post-stroke care continuity** [118].

6.2 Diagnostic Imaging Synergy

CT remains indispensable for its accessibility and speed in ruling out hemorrhage. However, **MRI has become the gold standard** for tissue viability assessment, penumbra quantification, and subtle lesion detection [119]. Combined imaging workflows — for example, **CT perfusion followed by DWI/PWI MRI** — provide complementary information for precise therapeutic decisions [120].

Artificial intelligence (AI)-assisted imaging now enables automated **ASPECTS scoring, infarct segmentation, and outcome prediction** [121]. Integration of these algorithms into emergency systems is redefining real-time diagnosis and triage efficiency.

6.3 Therapeutic Evolution

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The success of **mechanical thrombectomy** represents one of the greatest breakthroughs in stroke medicine. Extending the therapeutic window to 24 hours in selected patients (per DAWN and DEFUSE 3 trials) has saved thousands of patients from permanent disability (122, 123).

Additionally, **neuroprotective agents**, **stem cell-based therapies**, and **nanomedicine** are emerging frontiers. The challenge remains translating promising preclinical neurorestorative findings into consistent clinical efficacy (124).

Anticoagulant management has also evolved — **DOACs** have largely replaced warfarin for atrial fibrillation-related stroke prevention, offering improved safety and convenience (125).

6.4 Quality of Life as a Therapeutic Endpoint

Historically, stroke outcome measures focused on **mortality and motor recovery**. Today, **quality of life (QoL)**, psychological well-being, and social reintegration have gained prominence as key clinical endpoints (126).

Integrating **rehabilitation psychology**, **social support**, and **technology-assisted therapies** has improved long-term patient satisfaction and community reintegration (127). Rehabilitation research now embraces a **biopsychosocial model**, encompassing cognitive, emotional, and environmental domains (128).

6.5 Ethical and Policy Considerations

Global inequities persist: while high-income countries offer comprehensive stroke units and rehabilitation, low-resource regions face limited access to imaging, thrombolysis, and physiotherapy (129). Ethical imperatives include equitable access, fair allocation of high-cost interventions, and long-term care funding (130).

Public health strategies must prioritize:

- **National stroke registries** and **acute response systems**.
- **Public education** on early symptom recognition ("FAST" campaigns).
- **Integration of tele-rehabilitation** and low-cost community care models (131).

6.6 Challenges and Research Gaps

Despite progress, major challenges remain:

- **Limited time windows:** many patients still arrive beyond the therapeutic threshold.
- **Reperfusion injury:** post-recanalization oxidative stress and inflammation limit benefit.
- **Heterogeneous recovery:** neuroplastic potential varies across individuals.
- **Psychological sequelae:** depression and anxiety remain under-recognized.
- **Translational bottlenecks:** experimental therapies often fail in large-scale trials (132).

Future directions include:

- **AI-driven predictive modeling** of recovery outcomes.
- **Gene and cell-based neurorestoration.**
- **Wearable biosensors** for continuous monitoring of activity and vitals.
- **Integrated "stroke continuum" models**, linking acute, subacute, and chronic phases seamlessly (133).

VII. CLINICAL IMPLICATIONS

- **Early intervention:** "time is brain" remains central — protocols must ensure door-to-needle times <60 minutes.
- **Personalized imaging:** multimodal approaches refine treatment eligibility.
- **Holistic rehabilitation:** early initiation and continuity of multidisciplinary therapy improve QoL.
- **Telemedicine expansion:** essential for rural and underserved populations.
- **Long-term follow-up:** addressing mental health, caregiver support, and vocational reintegration (134).

VIII. CONCLUSION

Stroke management has transitioned into an era of **precision medicine** supported by imaging, technology, and neuroplasticity-driven rehabilitation. The convergence of **rapid diagnosis, advanced intervention, and long-term QoL enhancement** is redefining patient outcomes.

To sustain progress, emphasis must shift toward **universal accessibility, integrated care networks, and translational research.** The next decade holds promise for **AI-augmented diagnostics, personalized rehabilitation, and novel neurorestorative therapies** that could turn stroke from a disabling event into a largely recoverable condition.

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