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REVIEW ARTICLE

Novel robotic rehabilitation in Bangladesh: A narrative review

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Abstract

Background: Robotic rehabilitation has emerged as a transformative innovation in physical medicine, enabling high-intensity, task-specific, and measurable therapy that enhances neuroplasticity and functional recovery. This review summarises global evidence on robotic rehabilitation and examines its relevance and implementation challenges in low- and middle-income countries (LMICs), with a particular focus on the pioneering experience of the Bangladesh Medical University.

Methods: This narrative review synthesised literature from PubMed, Scopus, Web of Science, and Google Scholar published between January 2010 and September 2025. Included sources comprised reviews, meta-analyses, randomised controlled trials, observational studies, and policy documents addressing effectiveness, implementation, workforce, and health-system integration of robotic rehabilitation in LMICs. Evidence was thematically synthesised, prioritising higher-level studies, without formal PRISMA procedures or structured risk-of-bias assessment, consistent with accepted narrative review methodology.

Results: Global evidence supports robotic rehabilitation, with strongest benefits in stroke, moderate evidence in spinal cord injury, and emerging data in traumatic brain injury, neurodegenerative, paediatric, and musculoskeletal conditions. Effectiveness improves when robotics complement conventional therapy. In LMICs, adoption is hindered by financial, infrastructural, and workforce limitations. Bangladesh faces high disability burden and service gaps; the BMU Robotic Rehabilitation Centre represents a significant advancement in equitable, technology-driven rehabilitation.

Conclusion: Robotic rehabilitation offers measurable improvements in function and independence across diverse conditions. Strengthening infrastructure, workforce capacity, and policy support is essential for sustainable adoption in LMICs. The Bangladesh Medical University model demonstrates a feasible pathway for integrating advanced rehabilitation technologies in resource-constrained settings.

Key messages

The Robotic Rehabilitation Centre at Bangladesh Medical University, the nation's first university-affiliated facility for advanced rehabilitation, integrates high-intensity robotic therapy to improve outcomes for neurological and musculoskeletal disorders. Despite challenges of cost and access, it fosters research, innovation, and training, demonstrates a sustainable and technology-driven rehabilitation within LMIC settings.

Introduction

Rehabilitation medicine is transforming with robotic technologies that overcome limitations of conventional therapy, including therapist fatigue, limited intensity, and variability, enabling sustained, high-dose, task-specific training essential for neurological and musculoskeletal recovery. Robotic rehabilitation addresses many of these limitations by enabling standardised, intensive, repetitive, and data-driven therapy that can be individually tailored and objectively monitored. Devices such as exoskeletons, end-effector systems, robotic gait trainers, and sensor-based assistive platforms facilitate structured practice and real-time feedback, thereby supporting neuroplasticity and functional recovery [1-3].

Globally, disability remains a major public health concern. Stroke continues to be the leading cause of adult disability worldwide, while spinal cord injury (SCI), traumatic brain injury (TBI), neurodegenerative disorders, and musculoskeletal conditions contribute substantially to long-term functional impairment and reduced quality of life. The World Health Organization (WHO) estimates that more than one billion people live with some form of disability, with the greatest burden borne by low- and middle-income countries (LMICs) [4]. These regions face a dual challenge of rising non-communicable diseases and injury-related disability alongside constrained health-system resources.

Over the past two decades, robotic rehabilitation has been extensively studied in high-income countries (HICs). Evidence from systematic reviews and randomised controlled trials demonstrates improvements in upper-limb motor function, gait recovery, balance, and independence in activities of daily living when robotic interventions are combined with conventional therapy [5-8]. However, the translation of these advances into LMIC settings has been limited. Barriers include shortages of trained rehabilitation professionals, inadequate infrastructure, high acquisition and maintenance costs of robotic devices, lack of insurance coverage, and low public awareness of rehabilitation as a core component of health care.

Bangladesh exemplifies these challenges. Despite a high and growing burden of disability, rehabilitation services remain underdeveloped and unevenly distributed. In this context, Bangladesh Medical University (BMU) has established the country's first university-affiliated robotic rehabilitation centre. This initiative represents a significant institutional response to rehabilitation inequities and provides an opportunity to examine the feasibility, implementation, and early experience of robotic rehabilitation in a resource-constrained setting.

Methods

This study is a narrative review integrating peer-reviewed literature and relevant grey sources. Searches were conducted in PubMed, Scopus, Web of Science, and Google Scholar for publications between January 2010 and September 2025. Search terms included combinations of robotic rehabilitation, robot-assisted therapy, neurorehabilitation, stroke rehabilitation, spinal cord injury, LMIC rehabilitation, and Bangladesh rehabilitation.

Eligible sources included narrative and systematic reviews, meta-analyses, randomised controlled trials, large observational studies, and policy or guideline documents addressing clinical effectiveness, implementation, cost, workforce development, or health-system integration of robotic rehabilitation. Engineering-focused studies without clinical application, isolated case reports, and non-English publications without English abstracts were excluded.

Evidence was synthesised thematically, with emphasis on the strength and consistency of findings across conditions and relevance to LMIC contexts. Higher-level evidence (systematic reviews and meta-analyses) was prioritised where available. Formal PRISMA procedures, duplicate screening, or structured risk-of-bias scoring were not applied, in keeping with narrative review methodology.

Results

Global evidence on robotic rehabilitation

Robotic rehabilitation has evolved from experimental prototypes to clinically established tools across neurological, musculoskeletal, paediatric, and geriatric rehabilitation. The strength of evidence varies by condition, with the most robust data available for stroke, moderate evidence for SCI, and emerging evidence for other disorders.

Stroke rehabilitation

Stroke rehabilitation represents the most extensively studied application of robotic technologies. A large Cochrane review involving more than 7,000 participants demonstrated that electromechanical and robotic-assisted arm training significantly improves activities of daily living and upper-limb motor strength compared with usual care [2]. Robotic-assisted gait training has also been shown to improve walking independence, speed, and endurance, particularly in the subacute phase and when combined with body-weight support [6-8].

Randomised trials indicate that robotic therapy can deliver treatment intensities that are difficult to achieve with conventional therapy alone, while maintaining high patient motivation through interactive feedback. Importantly, robotic interventions appear most effective when integrated into comprehensive rehabilitation programmes rather than used as standalone treatments.

SCI

Exoskeleton-assisted walking has become a promising avenue in SCI rehabilitation. Evidence suggests improvements in cardiovascular endurance, bone density, and trunk control. Sale *et al.* [9] highlighted the role of robotic gait therapy in reducing secondary complications such as osteoporosis and pressure ulcers. A systematic review by Miller *et al.* [10] concluded that exoskeletons improved functional ambulation in selected SCI patients, although long-

Table 1 Gait and lower limb rehabilitation systems

Device names	Functions	Indications	Contraindications
ZEPU-AI1 (Gait Training & Evaluation System)	Robotic-assisted gait training with evaluation metrics	Stroke, spinal cord injury, TBI, Parkinson's, MS, CP, orthopedic recovery, balance disorders	Unstable fractures, severe spasticity, osteoporosis, DVT, uncontrolled epilepsy, open wounds
ZEPU-AI3 (Lower Limb Feedback Training System)	Active/passive stepping, lower limb strength evaluation	GBS, CIDP, SCI Myopathy, stroke, post-orthopedic surgery, early mobilization	Acute fractures, severe osteoporosis, severe dementia, pacemakers Bone malignancy, TB Severe cognitive impairment.
ZEPU-AI9 (Lower Limb Exoskeletal Gait Training System)	Exoskeleton-assisted walking	TBI, Stroke, SCI, CP, MS, PD, post-op mobilization, elderly with gait dysfunction, balance training	Severe spasms, unstable fractures, bone instability, skin ulcers, severe cognitive impairment
ZEPU-K2000E (Lower Limb Trainer)	Active/passive lower limb exercise	Stroke, SCI, TBI, post-surgical rehab, OA, fractures	Cardiopulmonary dysfunction, limb tumors, severe skin damage, TB

TBI indicates traumatic brain injury; MS, multiple sclerosis; CP, cerebral palsy; GBS, Guillain-Barré Syndrome; CIDP, chronic inflammatory demyelinating polyradiculoneuropathy; SCI, spinal cord injury; PD, Parkinson's disease; OA, osteoarthritis; DVT, deep vein thrombosis; TB, tuberculosis

term independence remained limited by injury severity. Nonetheless, patient satisfaction and quality of life outcomes were notably improved.

TBI

Compared with stroke and SCI, robotic rehabilitation in TBI has received less research attention. Emerging studies demonstrate improvements in gait symmetry, balance, postural control, and endurance following robotic gait training. Upper-limb robotic interventions show potential benefits in motor coordination and functional independence, although evidence remains limited to small trials and pilot studies [11]. Larger, well-designed studies are needed, particularly in LMICs where TBI burden is substantial due to road traffic accidents and occupational injuries.

Neurodegenerative disorders

Robotic rehabilitation is increasingly applied in neurodegenerative conditions such as Parkinson's disease and multiple sclerosis. In Parkinson's disease, robotic gait training reduces freezing episodes, improves stride length, and enhances balance [12]. In MS, robotic interventions improve walking speed, endurance, and fatigue resistance [13]. While evidence is less robust than for stroke, these findings support a complementary role for robotics in managing progressive neurological disorders.

Cerebral palsy

In paediatric cerebral palsy, robotic exoskeletons and robotic treadmills enable repetitive, engaging, task-specific training that is difficult to achieve manually. Studies demonstrate improvements in gait patterns, muscle strength, and gross motor function, particularly when robotic therapy is combined with conventional physiotherapy [14]. Robotic devices may also enhance motivation and adherence in children through interactive and gamified interfaces.

Musculoskeletal and orthopaedic rehabilitation

Robotic rehabilitation is increasingly used in musculoskeletal and post-operative care, including joint replacement, ligament reconstruction, and shoulder rehabilitation. These devices facilitate early mobilisation, graded loading, and precise range-of-motion control. Systematic reviews report reduced pain, improved joint mobility, and faster return to functional activities compared with standard therapy alone [15-17].

Table 2 Upper limb rehabilitation systems

Device names	Functions	Indications	Contraindications
ZEPU-AI2 (Upper extremity feedback training)	Repeated exercise training with proprioceptive feedback	Stroke, SCI, TBI, MS, Parkinson's, CP, orthopedic recovery, frozen shoulder	Acute fracture, tumors, severe osteoporosis, severe shoulder pain, pacemakers
ZEPU-AI6 Plus (3D Upper limb training system)	Active/passive 3D rehab (front-back, side-side, up-down)	Stroke, SCI, TBI, arthritis, CRPS, CP, prosthesis training, Adhesive capsulitis	Unstable fractures, tumors, severe spasticity, pacemakers, sever pain, TB, local infection
ZEPU-K2000D (Upper limb trainer)	Active/passive training for recovery	Stroke, TBI, orthopedic recovery, COPD, OA	Cardiopulmonary dysfunction, limb tumors, cognitive impairment
ZEPU-SG1 Plus (Hand function comprehensive training system)	Finger and hand function recovery	Stroke, SCI, CP, nerve injuries, RA, burns, MS, PD	Open wounds, unhealed fractures, severe cramps
ZEPU-K2000A (Upper/lower limb trainer)	Active/passive training, combined limbs	Stroke, CP, SCI, PD, post-fracture rehab, ICU deconditioning	Severe cardiopulmonary dysfunction, skin damage, severe joint deformities, open bleeding wounds

SCI indicates spinal cord injury; TBI, traumatic brain injury; MS, multiple sclerosis; CP, cerebral palsy; COPD, chronic obstructive Pulmonary disease; OA, osteoarthritis; PD, Parkinson's disease; ICU, intensive care unit; TB, tuberculosis

Table 3 Multi-joint and whole-body rehabilitation systems

Device names	Functions	Indications	Contraindications
ZEPU-AI4 (Multi-joint constant speed training system)	Isokinetic training and evaluation	Post-surgical rehab. Adhesive capsulitis stroke, SCI, ACL reconstruction, sports injury rehab	Acute fractures, tumors, severe osteoporosis, cognitive impairment Severe local inflammation, skin ulcers
ZEPU-AI7A (Upper & lower limb trainer)	Active/passive circular training	Stroke, SCI, Parkinson's, MS, CP, geriatric rehab, post-COVID weakness	Severe spasticity, unstable fractures, pacemakers
ZEPU-DK2 (Electric rehabilitation table)	Early mobilization, tilt and vibration	Stroke, SCI, TBI, arthritis, geriatrics, ICU patients	Hypotension, unstable fractures, severe heart failure, Severe joint deformities
ZP-PTC-3 (PT Training Bed)	Bed-based mobility, balance, transfer training	PD, CP stroke, paraplegia, quadriplegia, ICU early mobilization, post-operative rehabilitation	Unstable angina, DVT, severe osteoporosis, severe cognitive impairment

SCI indicates spinal cord injury; ACL, anterior cruciate ligament; MS, multiple sclerosis; CP, cerebral palsy; COVID, coronavirus disease; TBI, traumatic brain injury; ICU, intensive care unit; PD, Parkinson's disease; DVT, deep vein thrombosis

Cost-effectiveness and evidence gap

Although robotic rehabilitation requires substantial upfront investment, long-term benefits such as reduced disability, fewer complications, and decreased caregiver burden may render it cost-effective in high-burden conditions like stroke [3]. However, robust cost-effectiveness data from LMICs are lacking. Across conditions, effect sizes are often modest, device heterogeneity complicates comparisons, and long-term sustainability of gains remains uncertain.

Rehabilitation landscape in LMICs including Bangladesh

Despite a high burden of disability, rehabilitation services in LMICs remain underdeveloped. WHO estimates that more than 2.4 billion people could benefit from rehabilitation, the majority residing in LMICs [18]. Yet rehabilitation typically receives less than 2% of national health budgets, with services concentrated in urban tertiary centres [19]. Shortages of trained physiatrists, physiotherapists, occupational therapists, and speech therapists further limit access [20-22]. Out-of-pocket expenditure dominates health financing, and insurance coverage for rehabilitation is minimal [23]. In LMICs, stigma surrounding disability, low prioritisation of rehabilitation, and gender norms particularly restricting women's mobility and access to household resources significantly limit rehabilitation utilisation. In parallel, high device costs, limited technical expertise, unreliable electricity, poor internet access, and low digital literacy constrain adoption of robotic and tele-rehabilitation technologies [24-27].

In Bangladesh, stroke prevalence exceeds 11 per 1,000 population, contributing substantially to disability-adjusted life years lost [28]. Road traffic accidents and industrial injuries add to the burden of SCI and TBI. Musculoskeletal disorders, including osteoarthritis and low back pain, are leading causes of chronic disability. Despite this burden, Bangladesh has fewer than 400 registered physiatrists, and specialised rehabilitation centres are largely confined to Dhaka [29-31]. Community-based rehabilitation programmes exist but remain fragmented and underfunded [32]. Rehabilitation is not fully integrated into primary health care, and awareness remains low, particularly among women and rural populations [33-36].

Recent developments including endorsement of WHO Rehabilitation 2030, inclusion of rehabilitation in national policy documents, and expansion of telemedicine following the COVID-19 pandemic offer opportunities to strengthen rehabilitation delivery [37-38].

BMU robotic rehabilitation centre

Established in 2025, the BMU Robotic Rehabilitation Centre is the first university-affiliated facility of its kind in Bangladesh. The centre aims to integrate advanced rehabilitation technologies into clinical service delivery, education, and research. Its key functions include:

- Access: Introduction of advanced robotic rehabilitation previously unavailable in the country. This has improved access beyond affluent populations.
- Capacity building: Training of postgraduate medical students, physiatrists, and rehabilitation therapists.
- Research: Generation of local evidence on feasibility, outcomes, and implementation.

The centre houses 62 devices, among them 57 are robotic rehabilitation devices, and 22 are AI-enabled, covering upper-limb, lower-limb, multi-joint, and early -mobilisation applications.

Robotic therapy is delivered using a hybrid care model, complementing conventional physiotherapy and occupational therapy. Typical sessions involve 30–40 minutes of robotic training integrated into individualised rehabilitation plans based on functional status, affordability, and family support.

BMU has initiated observational data collection using validated outcome measures such as the Functional Independence Measure, Fugl–Meyer Assessment, Barthel Index, and six-minute walk test. Early experience suggests high patient motivation and acceptability, although formal effectiveness and cost-

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effectiveness analyses are ongoing.

Discussion

Despite its potential, robotic rehabilitation adoption in LMICs faces financial, infrastructural, workforce, cultural, and ethical barriers, requiring equitable, sustainable implementation strategies.

Financial and cost barriers

Robotic rehabilitation devices are capital-intensive, often costing between USD 100,000 and 300,000 for a single system. For resource-limited health systems, these costs compete with essential investments in acute care, medicines, and human resources [39]. Maintenance and servicing of devices add recurring expenses, while lack of local manufacturing inflates costs due to import taxes and logistics [40]. Minimal insurance coverage for rehabilitation in LMICs shifts costs to patients and families, disproportionately limiting access to advanced technologies to wealthier groups.

Infrastructure and technical challenges

Robotic rehabilitation requires stable electricity, technical expertise, and suitable infrastructure, which many LMIC facilities lack due to power, connectivity, and space constraints [41].

Workforce and training limitations

LMICs face severe shortages of rehabilitation professionals, with less than 10% of required workforce density compared to HICs [42]. Robotic rehabilitation demands additional training in device operation and safety, necessitating structured education, academic partnerships, and hands-on fellowship programs to prevent underutilization.

Cultural acceptance and patient perspectives

Cultural acceptance of robotics varies; enthusiasm for technology contrasts with distrust of machines, while gender norms may restrict women's participation, underscoring the need for awareness campaigns and family-centered counselling [43].

Policy and governance gaps

Rehabilitation is often neglected in LMIC health policies, with funding skewed toward acute care and infectious disease management [44]. Robotic rehabilitation requires long-term vision, national policy support, and integration into universal health coverage schemes. Without policy frameworks, centres may remain isolated pilot projects without scalability or sustainability.

Ethical considerations

Robotic rehabilitation raises important ethical issues: Equity: Risk of widening disparities if advanced technologies are limited to affluent patients. Consent and Autonomy: As a new device for human use the patients must understand the risks, limitations, and alternatives before consenting to robotic therapy. Data Privacy: Devices generate sensitive health data, which require secure storage and protection against misuse. · Prioritization of Resources: Ethical dilemmas arise when scarce funds are spent on robotics while basic rehabilitation services remain underfunded.

Sustainability concerns

Sustainability in LMICs requires management funds, local capacity building, and supply chain resilience. Public–private partnerships, philanthropic support, and domestic innovation may help reduce dependency on imported technology. Local universities and engineering institutions can collaborate with medical centres to design low-cost robotic prototypes adapted to regional needs [45].

Research gaps

Most clinical trials on robotics are conducted in HICs, raising concerns about external validity. LMIC-specific research is sparse, particularly regarding cost-effectiveness, patient satisfaction, and long-term functional outcomes [46]. Without locally generated data, policymakers and funders remain hesitant to scale up robotic rehabilitation.

Conclusion

Robotic rehabilitation improves motor recovery and independence, but its adoption in LMICs is limited by cost, infrastructure, and workforce constraints. The BMU Robotic Rehabilitation Centre demonstrates how advanced technologies can be integrated into resource -limited settings to strengthen access, equity, research, and capacity building.

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Author contributions

Concept and design, or design of the research; or the acquisition, analysis, or interpretation of data: MAS. MIH. *Drafting the manuscript or revising it critically for important intellectual content:* MIH, FN. *Final approval of the version to be published:* MAS, MIH, FN, MAKA. *Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved:* MAS, MAKA.

Conflict of interest

We do not have any conflict of interest.

Data availability statement

We confirm that the data supporting the findings of the study will be shared upon reasonable request.

Supplementary file

None

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