

REVIEW ARTICLE

Emerging rehabilitation technologies in Guillain–Barré syndrome: Advances, challenges, and future directions – A systematic scoping review

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Abstract

Background: Guillain–Barré syndrome (GBS) causes acute flaccid paralysis and long-term motor and functional deficits, often necessitating prolonged, multidisciplinary rehabilitation. In recent years, rapid advances in biomedical and digital technologies have broadened the therapeutic landscape for neurorehabilitation; however, their use and methodological quality in GBS have not yet been comprehensively reviewed. **Objective:** This scoping review systematically maps and synthesizes emerging rehabilitation technologies in GBS, grouping them into five clusters: robotics, electrical/biofeedback therapies, virtual and telerehabilitation, augmented reality/sensor-based systems, and hybrid/interactive platforms. It integrates both primary studies ($n = 18$) and systematic reviews ($n = 3$) to assess outcome trends (motor recovery, functional independence, and secondary measures such as quality of life, usability, and engagement) and to evaluate methodological quality using the Joanna Briggs Institute’s critical appraisal tools. **Relevance for patients:** The mapping of technologies demonstrated consistent improvements in motor recovery and functional outcomes among GBS survivors, especially with robotic and electrical/biofeedback therapies. High-quality evidence ($\geq 80\%$ “Yes”) predominated in this area, supporting the safe and effective integration of technology-based rehabilitation. The review highlights the clinical relevance of engineering-assisted, interactive strategies that foster adaptive, personalized recovery and enhance patient engagement throughout long-term neurorehabilitation.

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1. Introduction

Guillain–Barré syndrome (GBS) is an acute, immune-mediated polyradiculoneuropathy characterized by rapidly progressive, symmetrical weakness and areflexia.^{1,2} Although its annual incidence is relatively low—1–2 cases per 100,000 individuals—it remains the leading cause of acute flaccid paralysis worldwide.³ The clinical course of GBS is highly variable, ranging from mild weakness to complete paralysis requiring mechanical

ventilation. Following acute-phase immunomodulatory treatments, such as intravenous immunoglobulin or plasma exchange, comprehensive and sustained rehabilitation becomes essential for recovery. Its goals include restoring motor function, preventing or mitigating secondary complications such as contractures and pain, and ultimately promoting long-term functional independence and quality of life.⁴

1.1. Rationale for the review: Technology advances in neurorehabilitation and the evidence gap in Guillain-Barré syndrome

In recent years, the field of neurorehabilitation has undergone a technological revolution. Novel interventions are increasingly being integrated into the care of patients with neurological conditions, such as stroke, spinal cord injury, and multiple sclerosis.⁵⁻⁷ High-quality syntheses across neurological populations have confirmed this trend. For example, Hwang *et al.*,⁸ in a recent systematic review and meta-analysis on assistive and robotic technologies for upper-limb rehabilitation after stroke, demonstrated significant functional benefits while highlighting the diversity and maturity of emerging devices within neurorehabilitation contexts. This general evidence base underscores the translational relevance of technology-driven interventions beyond single disorders.

These emerging rehabilitation technologies, central to this review, are defined as advanced electronic, mechanical, or software-based platforms designed to deliver, augment, or monitor therapeutic interventions for functional recovery—representing a significant advancement beyond conventional rehabilitation modalities. For this review, the operational definition encompasses, but is not limited to:

- (i) Robotics and mechatronics: Robotic-assisted training for gait and upper-limb movements (e.g., exoskeletons and end-effector devices).
- (ii) Immersive and interactive technologies: Virtual reality (VR) and augmented reality (AR) systems that provide engaging, motivating, task-specific environments.
- (iii) Targeted neuromodulation: Stimulation methods include pharyngeal electrical stimulation (PES) for dysphagia management and non-invasive brain stimulation techniques such as transcranial magnetic stimulation.
- (iv) Advanced human-computer interfaces: Brain-computer interfaces (BCIs) that convert neural signals into external commands.
- (v) Remote and monitoring technologies: Wearable sensors for precise kinematic analysis and remote telerehabilitation platforms for therapy delivery.
- (vi) Intelligent systems: Artificial intelligence (AI)-driven

therapeutic or diagnostic algorithms that personalize treatment.

Unlike conventional modalities such as standard electrical stimulation, these technologies enable highly interactive, adaptive, and feedback-rich interventions, key principles for promoting neuroplastic change and functional recovery.⁹ Their application has yielded benefits in improving motor outcomes, enhancing patient engagement, and facilitating remote care in other neurological populations.⁵⁻⁷

Despite these advancements, their implementation in GBS rehabilitation remains poorly understood and insufficiently evaluated. Existing evidence appears fragmented, comprising mainly small-scale observational studies, case reports, and pilot trials. The heterogeneity of interventions, outcome measures, and populations creates a significant translational barrier. Clinicians currently lack an integrated body of evidence to guide decisions regarding which technology to apply, for which patient, and at what recovery stage. This evidence gap hampers the translation of GBS innovation into standard clinical care.

Recent systematic reviews further highlight this issue. For example, Toopchizadeh *et al.*¹⁰ focused on prognostic factors and concluded by emphasizing the need for further research into rehabilitation's role in reducing long-term disability. This clearly underscores the necessity for a structured, comprehensive mapping of the available interventions. A systematic evidence map is therefore urgently needed to delineate the breadth, nature, and direction of research on emerging technologies for GBS rehabilitation and to inform future innovation and clinical practice.

1.2. Preliminary search and positioning against existing reviews

A preliminary search of MEDLINE (via PubMed), the Cochrane Database of Systematic Reviews, and *JBI Evidence Synthesis* was conducted on August 1, 2025. This search confirmed the existence of relevant literature and identified several recent related reviews. While these reviews provide valuable insights, the present scoping review addresses a distinct and critical gap by offering a broader, methodologically rigorous, and clinically contextualized evidence map.

For example, Martino Cinnera *et al.*¹¹ focused narrowly on a single modality—robot-assisted therapy. In contrast, the current review adopts a wider scope, encompassing the full spectrum of emerging technologies beyond robotics alone. Similarly, Sulli *et al.*¹² restricted their analysis to randomized controlled trials (RCTs) assessing general rehabilitation efficacy. Conversely, the present scoping

review intentionally includes all study designs to capture the diversity of innovation, which frequently originates from non-RCT preliminary studies.

The review by Torres-Reyes *et al.*¹³ on biomedical engineering is thematically closest. Yet, our work differs fundamentally in focus and purpose. First, this review introduces a temporal boundary, limiting inclusion to studies published from 2015 onward to emphasize contemporary and truly emerging technologies—a forward-looking perspective absent in earlier reviews. Second, a more precise and clinically oriented conceptual framework is applied. While biomedical engineering encompasses a broad array of applications—from urinary devices to simulations—this review centers specifically on rehabilitation technologies (e.g., VR/AR, advanced robotics, BCI, PES, and telerehabilitation), ensuring direct clinical relevance. Third, this review's distinct value lies in its methodological rigor and transparency—conducted strictly under the Joanna Briggs Institute (JBI) scoping review methodology, guided by the population–concept–context (PCC) framework, contrasting with the narrative synthesis approach of Torres-Reyes *et al.*¹³ The data charting process systematically examines which technologies were used, in what clinical contexts (e.g., inpatient vs. community-based rehabilitation), and what outcomes were measured, offering a level of granularity previously lacking. Lastly, this review aims to maintain a direct focus on GBS-related data. While Torres-Reyes *et al.*^{13(p56)} acknowledged that “many of the studies did not have GBS patients as the center of the investigation,” the current review explicitly emphasizes studies in which GBS constituted the primary population or was adequately represented within mixed samples, enabling the extraction or inference of GBS-specific outcomes where possible.

In summary, by providing a methodologically robust, temporally focused, and conceptually precise overview of the latest rehabilitation technologies, this scoping review expands the current evidence landscape and delivers a consolidated, clinically meaningful foundation for advancing GBS rehabilitation research.

1.3. Justification for the scoping review method

A scoping review is the most appropriate methodology for the present objective, for several reasons. First, the topic is inherently broad, and available evidence is expected to vary widely in study design, intervention type, and outcome measures. A scoping review, unlike a systematic review, aims to map this diversity rather than answer a narrowly framed efficacy question. Second, the primary goal is to categorize the types and characteristics of available evidence and to highlight critical knowledge gaps

regarding novel rehabilitation technologies. This aligns directly with the exploratory nature of scoping reviews as defined by the *JBI Manual for Evidence Synthesis*.¹⁴ Third, by systematically charting data, the review lays the groundwork for future systematic or meta-analytic syntheses as sufficient evidence accumulates.

Building on these rationales, the present review was conducted following the *JBI Manual for Evidence Synthesis* (2020),¹⁴ which provides a structured yet flexible framework for scoping reviews. The inclusion of JBI guidance in this work does not reflect a formal appraisal process but serves to ensure transparent, systematic mapping of the available literature. As critical evaluation of individual study quality falls outside the purpose of scoping reviews, the JBI approach was applied here as an organizational supplement for data charting and synthesis. Given the fragmented and underdeveloped state of the literature, this design uniquely enables the consolidation of knowledge for clinicians, researchers, and policymakers engaged in advancing the rehabilitation of GBS survivors.

1.4. Review objective

This scoping review aims to systematically map and characterize the extent, range, and nature of the published literature on the use of emerging rehabilitation technologies for individuals with GBS across all phases of recovery. The primary objectives are to identify the types of advanced technologies being investigated, the clinical contexts of their application, the reported outcomes, and the existing gaps in the evidence base to inform future research and clinical innovation.

2. Methods and materials

2.1. Design

This study was conducted as a scoping review, guided by JBI methodology¹⁴ and reported in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) checklist.¹⁵ The review protocol was prospectively registered with the Open Science Framework (OSF) under the title “Emerging Rehabilitation Technologies in Guillain–Barré Syndrome: Advances, Challenges, and Future Directions,” available at <https://osf.io/fh49n>.

2.2. Eligibility criteria

The inclusion and exclusion criteria were defined following the PCC framework recommended by JBI's manual. Inclusion criteria were established as follows:

- (i) Studies involving individuals of any age or sex diagnosed with GBS or its clinical variants, including acute motor axonal neuropathy and acute

inflammatory demyelinating polyneuropathy.

- (ii) Studies evaluating any emerging rehabilitation technology, encompassing robotics, VR, AR, PES, BCIs, wearable or biofeedback systems, telerehabilitation platforms, and AI-based rehabilitation tools.
- (iii) Studies conducted in any clinical or community setting, including acute care, inpatient rehabilitation, outpatient, and home-based care.
- (iv) Peer-reviewed primary research articles and systematic reviews published in English between January 1, 2015, and September 30, 2025, encompassing quasi-experimental, cohort, case-control, and cross-sectional studies, as well as RCTs, case series, and case reports.

Exclusion criteria comprised:

- (i) Animal or preclinical studies.
- (ii) Editorials, commentaries, and letters to the editor.
- (iii) Conference abstracts without accessible full texts.
- (iv) Studies focusing solely on pharmacological or surgical interventions without any rehabilitation-technology component.

A comprehensive summary of these eligibility parameters is presented in [Table 1](#).

2.3. Information sources

A comprehensive search was conducted across five major electronic databases, PubMed/MEDLINE, Scopus, Cochrane Library, PEDro, and IEEE Xplore, to systematically identify relevant studies. Gray literature was explored through Google Scholar, and the reference lists of all included articles were screened to identify additional eligible sources.

2.4. Search strategy

The search strategy combined medical subject headings (MeSH) terms and free-text keywords related to GBS and rehabilitation technology. A representative PubMed search string was (“Guillain–Barré Syndrome”[MeSH] OR “GBS” OR “acute inflammatory demyelinating polyneuropathy”) AND (“robotics” OR “virtual reality” OR “brain–computer interface” OR “pharyngeal electrical stimulation” OR “telerehabilitation” OR “wearable technology” OR “artificial intelligence”). Equivalent strategies were adapted for the remaining databases.

2.5. Selection of sources of evidence

All records retrieved from the databases were imported into EndNote (v. X7, Clarivate, United Kingdom) for

Table 1. Eligibility criteria applied in the review

Criteria	Inclusion	Exclusion
Population	Patients with GBS or its variants (all ages, both sexes)	Non-human/Animal studies
Concept	Emerging rehabilitation technologies (e.g., robotics, VR/AR, PES, BCI, wearables, telerehabilitation, and AI tools)	Studies focusing solely on pharmacological or surgical management
Context	Acute, subacute, or chronic rehabilitation settings	Non-clinical or laboratory-based investigations without patient outcomes
Study types	Quasi-experimental, cohort, case-control, and cross-sectional studies, as well as RCTs, case series, case reports, and systematic reviews	Editorials, commentaries, conference abstracts without full text
Language/Date	English/Jan 2015–Sep 2025	Non-English/Outside the specified date range

Abbreviations: AI: Artificial intelligence; AR: Augmented reality; BCI: Brain–computer interface; GBS: Guillain–Barré syndrome; PES: Pharyngeal electrical stimulation; RCT: Randomized controlled trial; VR: Virtual reality.

de-duplication. Screening proceeded in two stages: (i) title and abstract screening and (ii) full-text assessment for potentially eligible records. Two reviewers (G.J. and S.B.) independently performed both stages; discrepancies were resolved by discussion or consultation with a third reviewer. Reasons for full-text exclusions were recorded systematically.

2.6. Data charting process

A pre-designed standardized data extraction form was used to chart all relevant information. Extracted data included: authorship, publication year, country, study design, sample size, participant characteristics (age, sex, GBS variant, and disease phase), details of technology type and technical specifications, intervention parameters (duration, frequency, intensity, and setting), outcome measures, and principal findings. Data extraction was independently conducted by two reviewers (G.J. and R.K.); discrepancies were resolved through consensus after double verification. To ensure consistency across heterogeneous designs, a two-level classification framework was applied:

- (i) Conceptual level, representing the translational stage of technology development; and
- (ii) Epidemiological level, reflecting study design and evidence strength.

At the conceptual level, a five-stage analytical framework was developed a priori for this research. Each study was categorized along a five-stage translational continuum (Stages I–V) representing progressive development and evaluation:

- Stage I. Feasibility and usability validation: Preliminary or mixed-method studies assessing feasibility, acceptability, and implementation practicality.
- Stage II. Prototype and technical validation: Engineering proof-of-concept or safety assessments.
- Stage III. Clinical efficacy and effectiveness testing: Interventional trials, randomized or non-randomized, examining therapeutic outcomes.
- Stage IV. Clinical observation and post-implementation: Descriptive case reports or real-world observational studies.
- Stage V. Evidence integration and synthesis: Systematic reviews or meta-analyses summarizing cumulative findings.

At the epidemiological level, each study was further classified by design type and empirical evidence strength using the Oxford Centre for Evidence-Based Medicine (OCEBM) 2011 hierarchy,¹⁶ aligned with JBI critical appraisal standards¹⁷: Level Ia = Systematic review/meta-analysis of RCTs; Level Ib = Single RCT; Level IIa = Systematic reviews of cohort studies; Level IIb = Non-

randomized (quasi experimental) trial; Level III = Mixed methods feasibility or retrospective cohort study; and Level IV = Single case design or case report.

This dual mapping provided an integrated synthesis of methodological diversity, linking technological maturity (Stages I–V) with evidence rigor, thereby enhancing interpretability and comparability across included studies.

2.7. Quality appraisal

Although formal critical appraisal is not mandatory for scoping reviews, a methodological quality assessment of the included studies was undertaken to enhance contextual interpretation. The JBI's critical appraisal tools¹⁷ were applied to each study type (e.g., RCTs, quasi-experimental studies, cohort studies, analytical cross-sectional studies, case series, and case reports). Two independent reviewers (G.J. and R.K.) completed the appropriate checklist for each study. Discrepancies were resolved through discussion; unresolved cases were adjudicated by a third reviewer. Each criterion was rated Yes (1), No (0), Unclear (0), or Not Applicable (excluded from the denominator), and total scores were expressed as the percentage of criteria met. Studies were categorized as:

- (i) High quality: ≥80% criteria met
- (ii) Moderate quality: 60–79% criteria met
- (iii) Low quality: <60% criteria met

3. Results

3.1. Selection of sources of evidence

The database search initially identified 783 records. After removing 254 duplicates, the titles and abstracts of 529 records were screened, and 23 full-text articles were assessed for eligibility. According to the predefined inclusion and exclusion criteria, 12 primary research studies and three systematic reviews met the eligibility requirements, encompassing research on rehabilitation interventions in GBS. In addition, the reference lists of the included systematic reviews were examined, resulting in the identification of six additional relevant studies, which were incorporated into the final synthesis. A PRISMA-ScR flow diagram¹⁸ illustrating the study selection process is shown in [Figure 1](#).

3.2. Characteristics of evidence sources

A total of 18 primary studies ([Table 2](#)) and 3 systematic reviews ([Table 3](#)) were included in the final synthesis. The primary studies comprised various designs, including RCTs, feasibility and pilot studies, mixed-methods research, and single-case or case-series reports, reflecting the exploratory nature of this research area. Publications spanned the period 2015–2025, with most studies

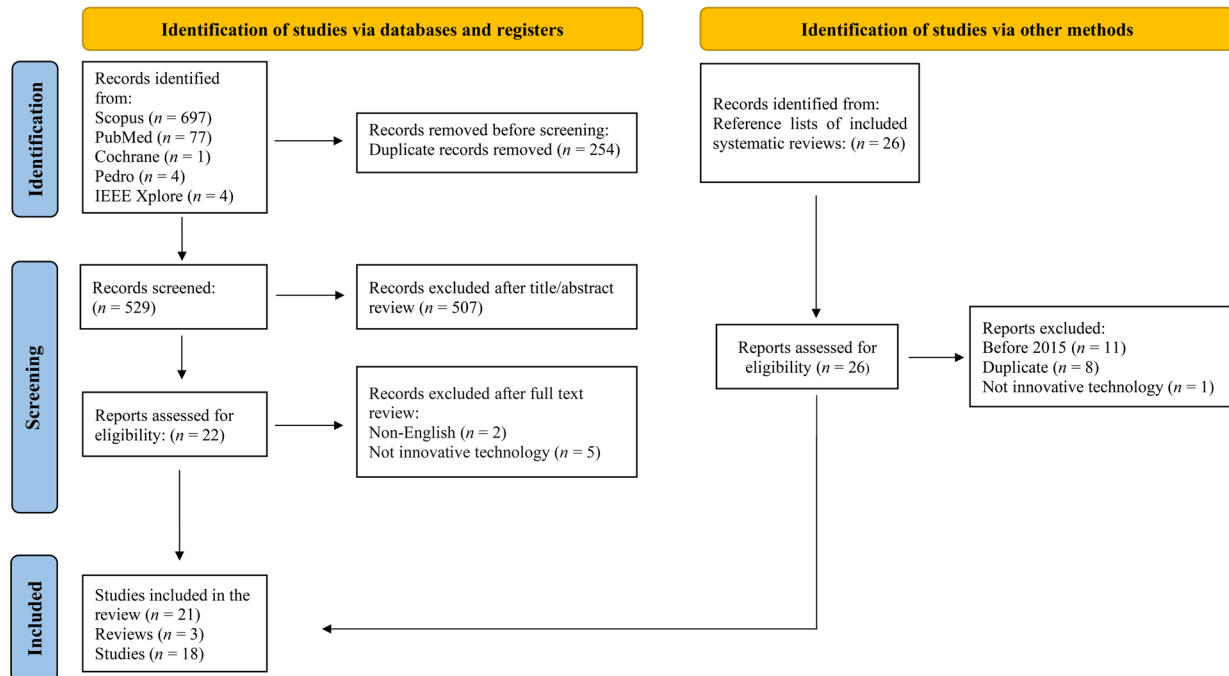


Figure 1. Preferred Reporting Items for Systematic reviews and Meta-Analyses for Scoping Reviews flow diagram illustrating the identification, screening, eligibility, and inclusion process for studies considered in the Guillain-Barré syndrome scoping review

originating from Asian (South Korea, Japan, China, India, and Taiwan) and European (Austria and Spain) centers.

Across studies, participants encompassed both adult and pediatric populations, with GBS diagnostic subtypes such as acute, chronic, and variant (e.g., pharyngeal-cervical-brachial GBS and Landry GBS) represented. The diversity of interventions aligned with emerging technology-based rehabilitation domains, including robotics (upper/lower limb, wearable, and AR-enhanced), electrical or biofeedback therapies, virtual and telerehabilitation, and exergaming systems.

3.3. Mapping of emerging rehabilitation technologies

The technological domains identified across the included primary studies are summarized in [Figure 2](#). The evidence mapping delineated five major categories of emerging rehabilitation technologies applied to GBS: (i) robotics, (ii) electrical/biofeedback therapies, (iii) virtual and telerehabilitation, (iv) AR/sensor-based systems, and (v) hybrid/interactive platforms.

3.4. Outcome mapping and comparative analysis

Across the included studies, motor recovery emerged as the most frequently targeted primary outcome, typically assessed through measures of muscle strength,

coordination, or gait performance. Improvements in functional independence, commonly evaluated via the functional independence measure and the Barthel Index, were also consistently reported. Several studies examined quality of life, while others addressed sensory recovery, swallowing ability, endurance, mobility, and user-centered metrics such as the engagement, usability, and acceptability of technology-assisted interventions. A comparative synthesis of the primary and secondary outcomes across technological domains is summarized in [Table 4](#).

3.5. Quality appraisal results

Of the included studies, 16 were rated as high, 4 as moderate, and 1 as non-applicable in terms of quality according to JBI's critical appraisal tools. Common methodological limitations included small sample sizes, lack of blinding, and short follow-up durations. A concise summary of the appraisal outcomes is presented in [Table 5](#).

4. Discussion

This scoping review synthesized 18 primary studies and 3 systematic reviews examining the application of emerging technologies in the rehabilitation of patients with GBS. The included studies covered a diverse range of modalities, including robotic-assisted rehabilitation, wearable sensors, targeted neuromodulation, and immersive technologies

Table 2. Characteristics of primary studies included in the scoping review

No.	Reference	Study design (type; evidence level per OCEBM 2023)	GBS sample (n/total)	Patient profile (GBS only)	Technology platform → Target function	Intervention details	Comparator	Key outcome measures	Main findings
Lower-/Upper-limb robotics									
1	Lee <i>et al.</i> ¹⁹	Prototype/ Proof-of-concept evaluation (experimental engineering; Level IV)	1/19	Adult males	Upper-limb robotics → Shoulder motion	Gravity-compensated passive shoulder joint tracker (3 sessions, ~30 min/session)	N/A	ROM, motion accuracy, energy efficiency	Device accurately tracked shoulder motion with minimal restriction vs. free movement; safe and mechanically efficient.
2	Cespedes <i>et al.</i> ²⁰	Prototype/ Proof-of-concept evaluation (Level IV)	1/4	Adults	Lower-limb robotics (sensors) → Posture/ Motivation	Lokomat RAGT with social robot (NAO) and HR feedback	RAGT without sensor feedback	Posture, HR, exertion, usefulness	Sensor-integrated RAGT improved posture without raising HR or fatigue; high user acceptance.
3	Choi <i>et al.</i> ²¹	Feasibility/ Clinical implementation study (single- arm pre-post interventional design; Level III)	7/189	Adults with heterogeneous neurological disorders	Lower-limb robotics → Gait	RAGT (Morning Walk®); flat/stair modes (24 sessions; 5x/week for ~5 weeks, 30 min/session)	N/A	Feasibility, safety, user feedback	RAGT is feasible and safe; saddle support enables use in non-ambulatory GBS patients; high tolerability observed.
4	Rhee <i>et al.</i> ²²	Feasibility/ Effectiveness evaluation (retrospective single-arm pre-post design; Level III)	15/15	Adults (≥19 y; mean age 55.7 y)	Lower-limb robotics → Gait	RAGT (Morning Walk®), 30 min/ session × 24 sessions + Standard rehabilitation	N/A	Strength, ambulation, mobility, ADL	Feasible and safe; significant gains in muscle power, mobility, walking endurance, and ADL; no adverse events.
5	Nehrujee <i>et al.</i> ²³	Prototype/ Usability validation (Level IV)	1/15	Not specified	Robotics (hand exoskeleton) → Upper-limb function	PLUTO device (single degree of freedom; 30-min sessions; game- based modes)	N/A	SUS, UEQ	Hand exoskeleton had acceptable usability (SUS = 73.8); rated positive for engagement; minor setup difficulties.

(Cont'd...)

Tabel 2. (Continued)

No.	Reference	Study design (type; evidence level per OCEBM 2023)	GBS sample (n/total)	Patient profile (GBS only)	Technology platform → Target function	Intervention details	Comparator	Key outcome measures	Main findings
6	Chrif <i>et al.</i> ²⁴	Prototype/Device usability and feasibility (Level IV)	1/5	Pediatric patients (14.8 y)	Interactive robotics (exergaming) → Leg press function	Pneumatic interactive leg press system; 40–45- min sessions, including exergames	N/A	SUS, feasibility, safety	System is feasible and safe; high motivation and therapist approval.
7	Fang <i>et al.</i> ²⁵	Prototype/ Proof-of-concept evaluation (Level IV)	1/3	Males (65 y; 5 y post-onset)	Wearable robotics → Ankle control	Adaptive bilateral exoskeleton, real-time controller (accuracy 72–90%), 40–45-min sessions	N/A	Ankle power, gait symmetry, efficiency	Exoskeleton enhanced ankle power (+72%), walking efficiency (+28%), and symmetry.
8	De Crignis <i>et al.</i> ²⁶	Prototype/ Comparative feasibility study (Level IV)	1/11	Adults	Upper-limb robotics + AR → Engagement	RobExReha robotic-AR game (4–5 sessions, ~45 min/session); adaptive support levels	Conventional system (ArmeoSprung)	Usability, workload, safety	AR-robot system was safe and feasible; enhanced engagement, though slightly lower usability than commercial units.
9	Chen <i>et al.</i> ²⁷	Clinical feasibility study (Level IV)	1/1	Females (75 y) with acute GBS (severe frailty)	Lower-limb robotics → Early mobilization	Lokomat RAGT + Multidisciplinary rehabilitation (2 sessions in treatment weeks 3 and 4)	Pre- intervention baseline	BI, IADL, CFS, MMT	RAGT was safe and facilitated early ambulation and motor recovery in frail GBS.
10	Hotz <i>et al.</i> ²⁸	Prospective convergent mixed- methods study (Level III)	2/26	Adults in the polyneuropathy subset	Lower-limb robotics → Gait/ Balance	RAGT (LEXO [®] ; 45 min, 4×/ week for 4 weeks) + Real- time feedback	N/A	Feasibility, safety, gait, balance, QoL	RAGT is highly accepted and safe; clinically improved gait and QoL.
11	Lee <i>et al.</i> ²⁹	Experimental feasibility (single- case design; Level IV)	1/1	A male (35 y) with IVIg treatment	Lower-limb robotics → Conditioning training	HUCA GAS100 RAGT; 3×/ week for 4 weeks; Phases 1–2 (70–85% HRR)	Pre- intervention baseline	Body comp, strength, gait, QoL	Safe and effective; improved muscle mass and exercise self-efficacy.

(Cont'd...)

Tabel 2. (Continued)

No.	Reference	Study design (type; evidence level per OCEBM 2023)	GBS sample (n/total)	Patient profile (GBS only)	Technology platform → Target function	Intervention details	Comparator	Key outcome measures	Main findings
12	Yabuki <i>et al.</i> ³⁰	Single-case clinical intervention (ABABA design; Level IV)	1/1	A male (78 y) with chronic GBS	Wearable exoskeleton → Hip gait training	HWA01 (hip assist robot); 5 days/week for 16 weeks; 20–30 min/session	Conventional gait program	CWS, stride, Cadence, 6MWT, modified FIM, ONLS	Gait parameters and mobility improved during exoskeleton phases; indicates wearable robots benefit chronic GBS.
Electrical/Biofeedback therapies									
13	Beirer <i>et al.</i> ³¹	Prospective case intervention (Level IV)	1/1	A male (74 y) with PCB GBS	PES → Swallow recovery	Phagenyx [®] ; 10 min/day for 3 days + Standard SLT	2 months of SLT alone	GUSS, FEES, decannulation rate	Rapid restoration of swallow function after PES; no effects after SLT alone.
14	Liu <i>et al.</i> ³²	Prospective non-randomized comparative study (Level IIb)	62/62	Pediatric patients (mean age 9.3 y)	EMG-biofeedback → Motor re-education	EMG-BFT (25 min, 6×/week for 12 weeks) + Standard rehabilitation	Standard rehabilitation only	Strength, GMFEM, BI	EMG-BFT enhanced strength and ADL independence vs. control.
15	Baršić <i>et al.</i> ³³	Single-case clinical intervention (Level IV)	1/2	A male (17 y) with CIDP/GBS	SCS → Pain relief	Epidural SCS implant after treatment failure	Pre-SCS baseline	Pain, ambulation, nerve fibers	SCS reduced pain and restored ambulation; nerve fiber regeneration was observed.

(Cont'd...)

Tabel 2. (Continued)

No.	Reference	Study design (type; evidence level per OCEBM 2023)	GBS sample (n/total)	Patient profile (GBS only)	Technology platform → Target function	Intervention details	Comparator	Key outcome measures	Main findings
Virtual rehabilitation & telerehabilitation									
16	Albiol-Pérez <i>et al.</i> ³⁴	Two-case pre-post interventional study (Level IV)	2/2	Adults with sub-acute GBS	VR → Balance/ Postural control	ABAR system (Nintendo Wii + Custom VR games); 20 sessions (delivered three times per week) + Conventional therapy	N/A	BBS, TUG, BI, SEQ	ABAR VR was feasible, safe, motivating; significantly improved postural control and engagement.
17	Khanna <i>et al.</i> ³⁵	Retrospective descriptive feasibility audit (Level III)	NR/37	Adults with heterogeneous neurological disorders	Telerehabilitation → Care delivery model	4-year hub-and-spoke TNR (network-based video consultation)	N/A	Feasibility, cost-uptake, cost-effectiveness	TNR model is feasible and cost-effective for neurological rehabilitation in resource-limited settings.
18	Paravalika <i>et al.</i> ³⁶	Pragmatic prospective parallel open-label RCT (Level Ib)	50/50	Pediatric patients (≤12 y; mean age 6.4 y)	Telerehabilitation → Functional recovery	24-week structured home telerehabilitation + Weekly video consultations with parent education	In-person rehabilitation	Strength, Hughes grade, ambulation rate	Telerehabilitation is non-inferior to conventional therapy; compliance is 96%; significant functional improvement.

Abbreviations: 6MWT: 6-minute walk test; ADL: Activities of daily living; AR: Augmented reality; BBS: Berg Balance Scale; BI: Barthel Index; CIDP: Chronic inflammatory demyelinating polyneuropathy; CWS: Continuous walking speed; EMG-BFT: Electromyographic-biofeedback therapy; FIM: Functional independence measure; GBS: Guillain-Barré Syndrome; GMFM: Gross motor function measure; HR: Heart rate; HRR: Heart rate reserve; IADL: Instrumental activities of daily living; IVIg: Intravenous immunoglobulin; MMT: Manual muscle test; N/A: Not applicable; NR: Not reported; OCEBM: Oxford Centre for Evidence-Based Medicine; ONLS: Overall neuropathy limitation scale; PCB: Pharyngeal–cervical–brachial variant; PES: Pharyngeal electrical stimulation; QoL: Quality of life; RAGT: Robot-assisted gait training; RCT: Randomized controlled trial; ROM: Range of motion; SCS: Spinal cord stimulation; SEQ: Subjective experience questionnaire; SLT: Speech and language therapy; SUS: System usability scale; TNR: Teleneurorehabilitation; TUG: Timed up and go; UEQ: User experience questionnaire; VR: Virtual reality.

Table 3. Characteristics of systematic reviews included in the scoping review

No.	Reference	Review type	Target population	Scope of technologies/ interventions	Synthesized key findings
1	Sulli <i>et al.</i> ¹²	Systematic review of RCTs	GBS patients	General rehabilitation (high-intensity exercise, cycling, electrical stimulation)	Seven RCTs provided moderate-quality evidence that multidisciplinary high-intensity rehabilitation improves short-term disability. Evidence for other modalities (e.g., cycling + stimulation) remains low to very low.
2	Martino Cinnera <i>et al.</i> ¹¹	Systematic review & protocol	GBS patients	Robotic therapy (RAGT; upper- and lower-limb robots)	Only 3 primary studies (2 case reports + 1 case series; $n = 4$ patients) were identified. Evidence for robotic rehabilitation in GBS is extremely limited and of low quality, underscoring a critical research gap.
3	Torres-Reyes <i>et al.</i> ¹³	Systematic review	GBS patients	Biomedical engineering technologies (VR, robotics, FES, telerehabilitation, orthoses)	Fourteen low-quality case studies highlighted emerging but weak evidence for biomedical technologies in GBS rehabilitation. Findings call for methodologically rigorous trials to validate efficacy.

Abbreviations: FES: Functional electrical stimulation; GBS: Guillain–Barré syndrome; RAGT: Robot-assisted gait training; RCT: Randomized controlled trial; VR: Virtual reality.

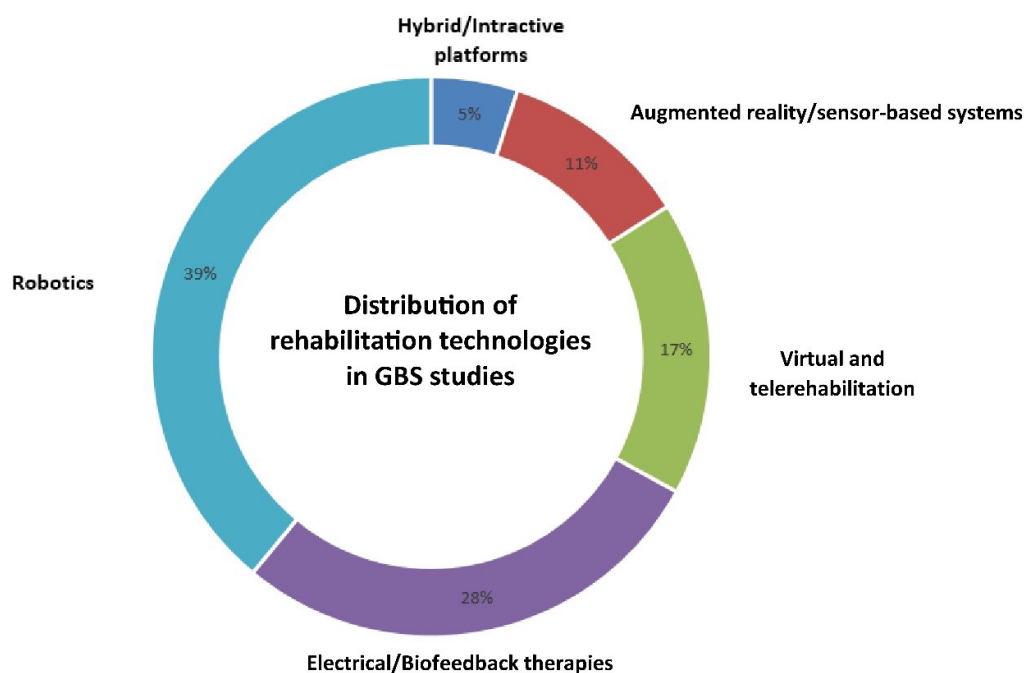


Figure 2. Mapping of emerging rehabilitation technologies in Guillain–Barré syndrome (GBS). The figure visually presents the proportional distribution of included primary studies by technological domain: Robotics (39%), Electrical/Biofeedback therapies (28%), Virtual and telerehabilitation (17%), Augmented reality/sensor-based systems (11%), and Hybrid/Interactive platforms (5%). Image created by the authors.

Table 4. Summary of primary and secondary outcomes reported across emerging rehabilitation technologies in Guillain-Barré syndrome

Technology category	No. of studies	Primary outcomes	Secondary outcomes	Common limitations
Robotics	7	Motor recovery, gait speed, ADL independence	Balance, QoL	Small samples; short-term duration
Electrical/Biofeedback therapies	5	Muscle strength, swallowing, sensory re-education	Endurance, fatigue management	Protocol heterogeneity; limited follow-up
Virtual & telerehabilitation	3	Engagement, functional performance	Usability, adherence	Technology barriers; connectivity issues
Augmented reality/Sensor-based systems	2	Fine motor control, hand-eye coordination	User satisfaction	Prototype feasibility; limited replication
Hybrid/Interactive platforms	1	Motivation, participation	QoL trend	Single-case design; low generalizability

Abbreviations: ADL: Activities of daily living; QoL: Quality of Life.

such as VR, AR, and telerehabilitation platforms. While traditional immunotherapy remains the cornerstone of acute-phase management, these innovations aim to support long-term functional recovery. Collectively, the findings revealed a growing—though still limited—body of evidence supporting the feasibility and safety of these technological interventions. Evidence for efficacy remains preliminary, with most studies constrained by small sample sizes and heterogeneous designs. Thus, while the trajectory suggests meaningful potential for integrating advanced technologies into GBS rehabilitation protocols, definitive conclusions regarding effectiveness cannot yet be drawn.

4.1. Robotic-assisted rehabilitation: Feasibility and functional gains

Robot-assisted gait training is the most frequently studied intervention, primarily used for lower-limb rehabilitation with a focus on walking. Devices such as Morning Walk®, Lokomat, HUCA GAS100, and other wearable exoskeletons were implemented across clinical and research settings. Most studies reported improvements in muscle strength, gait symmetry and efficiency, postural control, gait biomechanics, balance, and activities of daily living (ADL). These interventions were generally well tolerated and well accepted by patients.^{20–23,27–30}

Upper-limb robotics, though less extensively investigated, yielded promising results in terms of feasibility, usability, and movement precision. For example, Lee *et al.*¹⁹ developed a passive shoulder joint tracking module that facilitates more natural shoulder motion by allowing three-dimensional translation and reducing interaction forces. Nehrujee *et al.*²³ introduced PLUTO, a modular hand rehabilitation robot integrated with adaptive computer games, which received favorable usability ratings from patients, caregivers, and clinicians. Additionally, De Crignis *et al.*²⁶ evaluated the RobExReha system—an AR-enhanced robotic arm platform—and found it to be safe, engaging, and technically feasible for upper-limb rehabilitation.

4.2. Biofeedback and neuromodulation: Enhancing recovery pathways

Electrical/Biofeedback therapies were explored in three studies, each targeting distinct clinical challenges. Liu *et al.*³² conducted an RCT in pediatric GBS patients, demonstrating that electromyographic-biofeedback therapy significantly improved muscle strength, gross motor function, and ADL independence compared with routine physical and occupational therapy. These findings suggest that biofeedback may accelerate neuromuscular

Table 5. Summary of methodological quality and risk of bias across included studies in this review

Reference	Conceptual category	Epidemiological design	Evidence level (OCEBM 2023)	JBI critical appraisal tools	Percentage of "Yes" (%)	Risk of bias (quality)
Primary studies						
Albiol-Pérez <i>et al.</i> ³⁴	Stage I: Feasibility & usability validation	Retrospective feasibility & service implementation study (TNR India)	Level III	JBI checklist for case reports	~85	Low risk of bias (high quality)
Khana <i>et al.</i> ³⁵	Stage IV: Clinical observation & post-implementation	Clinical case report (PES in PCBGBS)	Level IV	JBI checklist for analytical cross-sectional studies/service implementation	~83	Low risk of bias (high quality)
Lee <i>et al.</i> ¹⁹	Stage I: Feasibility & usability validation	Non-randomized controlled feasibility trial (quasi-experimental study)	Level IIb	JBI checklist for analytical cross-sectional studies	N/A (~descriptive engineering)	N/A/Nonclinical evidence
Beirer <i>et al.</i> ³¹	Stage II: Prototype & technical validation	Proof-of-concept study with cross-sectional usability data	Level III	JBI checklist for case reports	~88	Low risk of bias (high quality)
Céspedes <i>et al.</i> ²⁰	Stage IV: Clinical observation & post-implementation	Single-case clinical design (case report)	Level IV	JBI checklist for analytical cross-sectional studies (applicable to within-subject comparisons)	~80 (adjusted)	Low-moderate risk of bias due to small sample and short duration (moderate quality)
Choi <i>et al.</i> ²¹	Stage I: Feasibility & usability validation	Convergent mixed-methods feasibility study	Level III	JBI checklist for quasi-experimental studies	~88	Low risk of bias (high quality)
Rhee <i>et al.</i> ²²	Stage I: Feasibility & usability validation	Cross-sectional usability evaluation (mixed methods)	Level III	JBI checklist for quasi-experimental studies	~85	Low risk of bias (high quality)
Liu <i>et al.</i> ³²	Stage III: Clinical efficacy & effectiveness testing	Non-randomized comparative controlled trial (EMGBF pediatric GBS)	Level IIb	JBI checklist for quasi-experimental studies	~82	Low risk of bias (high quality)
Nehrujee <i>et al.</i> ²³	Stage IV: Clinical observation & post-implementation	Single-case intervention report (RAGT)	Level IV	JBI checklist for analytical cross-sectional studies	~85	Low risk of bias (high quality)

(cont'd...)

Table 5. (Continued)

Reference	Conceptual category	Epidemiological design	Evidence level (OCEBM 2023)	JBI critical appraisal tools	Percentage of "Yes" (%)	Risk of bias (quality)
Cherif <i>et al.</i> ²⁴	Stage I: Feasibility & usability validation	Convergent mixed-methods feasibility study (RAGT LEXO*)	Level III	JBI checklist for analytical cross-sectional studies (appropriate for single-session observational usability)	~80	Low-moderate risk of bias with excellent transparency and limited statistical power (moderate quality)
Fang <i>et al.</i> ²⁵	Stage IV: Clinical observation & post-implementation	Clinical case report (CARE guideline)	Level IV	JBI checklist for case series	~80	Low-moderate risk of bias due to small sample size and heterogeneous presentations (moderate quality)
De Crignis <i>et al.</i> ²⁶	Stage IV: Clinical observation & post-implementation	Clinical case report (HUCA GAS100 device)	Level IV	JBI checklist for quasi-experimental studies (nonequivalent comparison groups)	~85	Low risk of bias (high quality)
Chen <i>et al.</i> ²⁷	Stage II: Prototype & technical validation	Engineering prototype testing (usability and functionality)	Levels IIb-III	JBI checklist for case reports	~85	Low risk of bias (high quality)
Hotz <i>et al.</i> ²⁸	Stage I: Feasibility & usability validation	Retrospective service implementation study (hub-and-spoke TNR)	Level III	JBI checklist for quasi-experimental studies	~85	Low risk of bias (high quality)
Lee <i>et al.</i> ²⁹	Stage IV: Clinical observation & post-implementation	Two-case clinical intervention report (SCS for GBS/CIDP)	Level IV	JBI checklist for case reports	~88	Low risk of bias (high quality)
Paravalka <i>et al.</i> ³⁶	Stage III: Clinical efficacy & effectiveness testing	Prospective parallel open-label RCTs (telerehabilitation LGBS)	Level Ib	JBI checklist for RCTs	~87	Low risk of bias (high quality)
Yabuki <i>et al.</i> ³⁰	Stage III: Clinical efficacy & effectiveness testing	Non-randomized two-arm controlled trial (EMGBF vs. PT/OT)	Level IIb	JBI checklist for case reports	~88	Low risk of bias (high quality)
Barisic <i>et al.</i> ³³	Stage IV: Clinical observation & post-implementation	Single-case clinical intervention study (SCS GBS/CIDP residual)	Level IV	JBI checklist for case reports	~86	Low risk of bias (high quality)

(contd...)

Table 5. (Continued)

Reference	Conceptual category	Epidemiological design	Evidence level (OCEBM 2023)	JBIC critical appraisal tools	Percentage of "Yes" (%)	Risk of bias (quality)
Systematic reviews						
Sulli <i>et al.</i> ¹²	Stage V: Evidence synthesis & clinical translation	Systematic review of RCTs	Level Ia	JBIC checklist for systematic reviews and research syntheses	~70	Moderate risk of bias (moderate quality)
Martino Cinnera <i>et al.</i> ¹¹	Stage V: Evidence synthesis & clinical translation	Systematic review with registered protocol and integrated RCT protocol	Level Ia	JBIC checklist for systematic reviews and research syntheses	~81	Low risk of bias (high quality)
Torres-Reyes <i>et al.</i> ¹³	Stage V: Evidence synthesis & technology mapping	Systematic review of quantitative studies	Level Ia	JBIC checklist for systematic reviews and research syntheses	~90	Low risk of bias (high quality)

Abbreviations: CARE: CAsE REport checklist; CIDP: Chronic inflammatory demyelinating polyneuropathy; EMG-BF: Electromyographic-biofeedback; GBS: Guillain-Barré syndrome; JBI: Joanna Briggs Institute; LGBS: Landry-Guillain-Barré syndrome; N/A: Not applicable; OCEBM: Oxford Centre for Evidence-Based Medicine; OT: Occupational therapy; PCB: Pharyngeal-cervical-brachial variant; PES: Pharyngeal electrical stimulation; PT: Physiotherapy; RAGT: Robot-assisted gait training; RCT: Randomized controlled trial; SCS: Spinal cord stimulation; TNR: Teleneurorehabilitation.

recovery and enhance the effectiveness of conventional rehabilitation.

In the domain of neuromodulation, Beirer *et al.*³¹ also reported the successful use of PES in a patient with the pharyngeal–cervical–brachial variant of GBS and therapy-resistant dysphagia. The patient achieved safe tracheostomy decannulation after just three sessions of PES, despite no prior response to two months of standard speech and language therapy. Additionally, Barisic *et al.*³³ described spinal cord stimulation as a last-resort intervention for chronic neuropathic pain in a patient with GBS/chronic inflammatory demyelinating polyneuropathy, resulting in pain relief, improved ambulation, and signs of peripheral nerve regeneration.

4.3. Virtual reality and gamified systems

Virtual reality and interactive exergaming systems were evaluated in two studies, both of which reported positive outcomes in balance, gait, and patient motivation. Albiol-Pérez *et al.*³⁴ demonstrated that a VR-based balance training system (ABAR + Wii Balance Board) improved balance and ADL function in two GBS patients, with high usability and engagement. Similarly, Cherif *et al.*²⁴ found that a pneumatic robotic leg press with exergames was safe, technically feasible, and highly motivating for a pediatric GBS patient.

4.4. Teleneurorehabilitation: Expanding access in resource-limited settings

Two studies investigated teleneurorehabilitation models, particularly in low-resource contexts. Khanna *et al.*³⁵ and Paravalika *et al.*³⁶ demonstrated that telerehabilitation is both feasible and cost-effective, with high patient compliance and outcomes comparable to in-person rehabilitation in both adult and pediatric populations. In the study by Paravalika *et al.*,³⁶ children receiving weekly video consultations and parent-guided home exercises achieved improvements in strength and ambulation similar to those in conventional programs.³⁶

4.5. Comparison with previous reviews

These findings are broadly aligned with the conclusions of the three previous systematic reviews. However, our approach differs in both scope and methodology. Martino Cinnera *et al.*¹¹ focused exclusively on robot-assisted therapy, while Sulli *et al.*¹² limited their analysis to RCTs assessing general rehabilitation. In contrast, our scoping review encompassed a wider spectrum of emerging technologies and included diverse study designs. Torres-Reyes *et al.*¹³ examined biomedical engineering applications more generally, whereas our review offers a

targeted synthesis of their clinical relevance specifically within the context of GBS. Despite these methodological differences, all reviews converge on a shared conclusion: technology-driven interventions hold significant promise for advancing rehabilitation in GBS.

4.6. Critical appraisal and methodological considerations

While the reported outcomes are encouraging, they must be interpreted with caution. Many of the included studies were single-case reports, involved heterogeneous populations, or lacked sufficient detail regarding the interventions, all of which may have contributed to overly optimistic conclusions. Although we applied JBI's critical appraisal tools to assess study quality, its relatively lenient criteria may have led to studies being classified as acceptable despite notable methodological limitations. In contrast, more rigorous instruments, such as the Cochrane Risk of Bias Tool (RoB) and its updated version, the Revised Cochrane Risk of Bias Tool for Randomized Trials (RoB 2), impose stricter thresholds for evaluating internal validity and might have yielded more conservative assessments.

However, as outlined in the introduction, this review was not intended to conduct a formal risk-of-bias analysis or effectiveness synthesis, as would be expected in a systematic review. Given the heterogeneity of study designs and the exploratory nature of the topic, a scoping review was the most appropriate methodological approach. While critical appraisal is not a mandatory component of scoping reviews, we included a basic quality assessment using JBI's tools to provide contextual insight into the strengths and limitations of the available evidence and to support interpretation. These considerations further underscore the need for high-quality, well-powered trials to substantiate the clinical utility and long-term impact of emerging technologies in GBS rehabilitation.

4.7. Limitations and future directions

Despite promising trends, several limitations were consistently observed across the reviewed studies. First, the number of rehabilitation sessions was often unspecified, making it difficult to assess intervention intensity and duration. The disease phase—whether acute, subacute, or chronic—was frequently omitted or vaguely described, limiting the ability to contextualize outcomes based on recovery stage. Many studies also lacked detailed descriptions of the exercises or protocols used alongside the technologies, thereby hindering reproducibility and clinical translation.

Sample sizes were generally small, with GBS patients often included as a minor subset within broader

neurological cohorts. This restricts statistical power and limits the generalizability of findings. Most studies were case reports, pilot trials, or feasibility studies with heterogeneous methodologies. As emphasized in prior reviews, there is a pressing need for high-quality RCTs to rigorously evaluate the efficacy of these interventions and establish standardized treatment protocols.

Additionally, the nature of the rehabilitation tasks was not consistently defined. While most lower-limb interventions focused on gait-related impairments, other functional activities—such as sit-to-stand transitions or stair climbing—were rarely assessed, despite their relevance to daily mobility. Similarly, upper-limb tasks were often limited to isolated joint movements rather than functional, task-oriented exercises that reflect real-world use.

Another notable gap lies in the diversity and standardization of outcome measures. Few studies incorporated comprehensive assessments across motor, psychosocial, or biomechanical domains, nor did they consistently align with frameworks such as the International Classification of Functioning, Disability and Health (ICF). Finally, economic considerations were largely absent. Given the potential cost implications of implementing advanced technologies in clinical settings, future research should include cost-effectiveness analyses to support informed decision-making and facilitate broader adoption.

5. Conclusion

This scoping review highlights the growing interest and promising potential of emerging technologies in the rehabilitation of GBS, including robotic systems, neuromodulation, virtual environments, and telerehabilitation platforms. Current evidence primarily supports feasibility, safety, and patient acceptability, with preliminary indications of functional motor improvement and greater rehabilitation engagement. Nevertheless, the evidence base remains fragmented and methodologically limited, with most studies constrained by small sample sizes, heterogeneous populations, and insufficient detail regarding intervention protocols. These limitations restrict reproducibility and preclude definitive conclusions regarding clinical efficacy. To advance the field, future research should prioritize well-designed RCTs with clearly defined rehabilitation tasks, comprehensive and multidimensional outcome measures, and economic evaluations. Addressing these gaps will be essential to move beyond exploratory feasibility studies toward clinically validated, evidence-based models for integrating advanced technologies into GBS rehabilitation.

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Conflict of interest

The authors declare that they have no competing interests.

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Ethics approval and consent to participate

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Availability of data

The data will be made available upon reasonable request to the corresponding author.

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