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Functional electrical stimulation-assisted cycling in sclerosis

Feasibility and apparent safety of functional electrical stimulation-assisted cycling in amyotrophic lateral sclerosis and primary lateral sclerosis: a single-arm longitudinal pilot feasibility study

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Abstract

Functional electrical stimulation-assisted cycling may be relevant in motor neuron disease, but its feasibility and safety in amyotrophic lateral sclerosis and primary lateral sclerosis remain unclear. The authors aimed to assess feasibility, apparent safety, and exploratory pre-post clinical changes of a three-week functional electrical stimulation-assisted cycling protocol in ambulatory inpatients with amyotrophic lateral sclerosis or primary lateral sclerosis. Fifteen patients were assessed; 11 were enrolled (5 ALS, 6 PLS) and received 15 supervised 30-minute FES-cycling sessions over three weeks in addition to conventional neuromotor rehabilitation. Bilateral eight-channel stimulation targeted quadriceps, tibialis anterior, hamstrings, and gastrocnemius during active or active-assisted cycling. Feasibility outcomes were enrollment, completion, tolerance, adverse events, and pre-post data availability. Clinical outcomes were analyzed descriptively. Eleven of 15 assessed patients were enrolled (73.3%; 5 ALS, 6 PLS). All enrolled participants completed the protocol, no adverse events were documented, and complete pre-post data were available. Exploratory outcomes showed favorable short-term changes in mobility, walking, strength, and spasticity. This protocol appears feasible and

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apparently safe in selected ambulatory inpatients. Findings are hypothesis-generating and support a prospective controlled feasibility trial before efficacy is tested.

Key words: amyotrophic lateral sclerosis; primary lateral sclerosis; functional electrical stimulation; neurorehabilitation; feasibility; apparent safety.

Amyotrophic Lateral Sclerosis (ALS) is a progressive motor neuron disease characterized by heterogeneous upper and lower motor neuron involvement, progressive weakness, impaired mobility, fatigue, respiratory complications, and increasing loss of autonomy.^{1,2} Primary Lateral Sclerosis (PLS) is a rarer upper motor neuron syndrome with a slower clinical course, but it may still lead to spasticity, gait impairment, fatigue, and functional dependence.³⁻⁵ Current guidelines emphasize multidisciplinary care and symptom-oriented management throughout the disease trajectory. Within this framework, rehabilitation aims to preserve function, prevent secondary complications, support participation, and adapt care to progressive disability.^{3,6,7}

Exercise prescription in motor neuron disease remains clinically delicate. The Cochrane review on therapeutic exercise in ALS found limited randomized evidence and concluded that appropriately monitored exercise may be feasible, although the certainty of evidence remains low.⁸ More recent trials and reviews support the safety and potential benefit of moderate, individualized programmes, including resistance, endurance, and combined training, while continuing to stress careful monitoring and avoidance of excessive fatigue, overwork, and inappropriate intensity.⁹⁻¹¹ This context is central to the present study: before any technology-assisted rehabilitation intervention in ALS or PLS can be tested for efficacy, it must first be shown to be deliverable, tolerable, and apparently safe in clinically eligible patients.

Functional Electrical Stimulation-assisted cycling (FES-cycling) combines repeated lower-limb cycling with electrically elicited muscle contractions synchronized with the pedalling cycle. Neuromuscular electrical stimulation may facilitate muscle activation and influence circulation, muscle conditioning, sensory afferent input, and task-related practice.¹² FES-cycling has been studied more extensively in stroke, multiple sclerosis, spinal cord injury, and myotonic dystrophy type 1 than in motor neuron disease.¹³⁻¹⁹ Findings from these populations provide useful external plausibility, but they cannot be

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directly generalized to ALS or PLS because disease progression, denervation, fatigue, respiratory reserve, and safety margins differ substantially.

The rationale for translating FES-cycling to ALS and PLS is further supported by the recognition that skeletal muscle is not only a passive end-organ of denervation. Experimental work in Superoxide Dismutase 1 (SOD1)-related ALS models suggests that skeletal muscle may be involved in disease mechanisms beyond passive denervation and altered muscle-nerve communication.^{20,21} Nevertheless, these experimental findings do not imply that FES-cycling modifies ALS pathogenesis. Direct clinical evidence for electrical stimulation in ALS remains extremely limited, and previous ALS-specific evidence is largely restricted to a single case report of therapeutic electrical stimulation.²² Therefore, a feasibility-oriented step is required before controlled efficacy testing can be justified.

The present study was designed as a single-arm longitudinal pilot feasibility study. The primary aim was to assess the feasibility and apparent safety of a three-week FES-cycling protocol delivered during inpatient neurorehabilitation in ambulatory patients with ALS or PLS. The secondary aim was to explore pre-post changes in functional mobility, walking speed, walking endurance, lower-limb strength, and spasticity. Clinical outcomes were interpreted as preliminary signals only and not as confirmatory evidence of efficacy.

Materials and Methods

Study design and reporting framework

This was a single-arm longitudinal pilot feasibility study conducted in an inpatient neurorehabilitation setting. The analysis was based on a clinical cohort of patients with ALS or PLS who received FES-cycling as part of a structured rehabilitation programme. The methodological framing followed feasibility-study principles, according to which feasibility, safety, intervention delivery, and data completeness should be prioritized before efficacy claims are made.²³⁻²⁵ The intervention was described according to transparent intervention-reporting principles, including equipment, target muscles, stimulation parameters, dose, and delivery context.²⁶

Because no control group was included, all clinical analyses were considered exploratory. The study was not designed to estimate treatment efficacy or to isolate the specific contribution of FES-cycling from the effects of conventional neuromotor rehabilitation, spontaneous short-term fluctuation, repeated testing, or inpatient care.

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Setting and participants

Patients were recruited from the Amyotrophic Lateral Sclerosis Unit of the Neurorehabilitation Department at Ospedale San Camillo, Lido di Venezia, between January 2015 and September 2017. During this period, 15 potentially eligible patients were assessed for FES-cycling; 11 were enrolled in the treated cohort. The enrolled cohort consisted of five patients with ALS and six patients with PLS. The recruitment denominator was complete, but detailed reasons for non-enrollment of the remaining four patients were not available in the source data. Eligible participants had a diagnosis of ALS or PLS, were classified as Sinaki stage ≤ 4 , were able to perform the Timed Up and Go test and the 6-Minute Walk Test and were able to collaborate with treatment and assessment procedures, defined as a Mini-Mental State Examination score ≥ 24 . Exclusion criteria were concomitant orthopedic or musculoskeletal conditions interfering with lower-limb exercise and psychiatric conditions limiting participation.

All participants received information about the clinical assessment and treatment procedures and provided informed consent. Procedures were conducted in accordance with the Declaration of Helsinki. The investigation and use of patients' data for research purposes was approved by the local research ethics committee in accordance with Declaration of World Medical Association.

Eleven patients were enrolled: seven men and four women. Mean age was 59.5 years, and mean time from diagnosis was 4.5 years. Sex-stratified descriptive data were: men had a mean age of 64.1 years and a mean time from diagnosis of 4.8 years, whereas women had a mean age of 51.5 years and a mean time from diagnosis of 5.0 years. Baseline characteristics are summarized in Table 1.

Feasibility objectives and outcomes

The primary feasibility question was whether a three-week FES-cycling protocol could be delivered completely and without documented adverse events in ambulatory patients with ALS or PLS during inpatient rehabilitation. Feasibility domains were defined for the present feasibility-oriented report as eligibility among assessed candidates, intervention completion, treatment tolerance, apparent safety, and completeness of pre-post clinical outcome assessment.

Eligibility was defined as the proportion of assessed candidates who were enrolled in the treated cohort. Intervention completion was defined as completion of the planned 15-session protocol. Treatment tolerance was defined clinically as the ability to continue the protocol without discontinuation due to relevant intolerance, excessive fatigue, pain, device-related problems, or clinical deterioration. Fatigue and discomfort were monitored through therapist clinical observation and patient feedback during and

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after each session; no standardized fatigue or discomfort scale was used. Apparent safety was described according to documented adverse events during assessment or treatment. Feasibility outcomes are reported in the Results section.

Intervention

Participants received 15 FES-cycling sessions over three weeks, with five sessions per week. Each session lasted 30 minutes and included 5 minutes of active cycling without stimulation as warm-up, 20 minutes of active or active-assisted cycling combined with FES, and 5 minutes of active cycling without stimulation as a cool-down. The protocol was delivered in addition to one hour per day of conventional neuromotor rehabilitation, with no planned change in ongoing pharmacological treatment. Patients wore comfortable clothing suitable for electrode application, and the lower-limb skin was prepared to improve electrode adherence, including cleaning and, when needed, hair removal of the target regions.

FES-cycling was delivered using a MOTomed viva2 motorized cycle ergometer (RECK-Technik GmbH & Co. KG, Betzenweiler, Germany) connected to an eight-channel RehaStim2 stimulator (Hasomed GmbH, Magdeburg, Germany). Surface adhesive gel electrodes were used for each patient. Electrodes were positioned bilaterally over the quadriceps, tibialis anterior, hamstrings, and gastrocnemius muscles, with the positive electrode placed proximally and the negative electrode distally. Large electrodes (9.5 x 4.5 cm) were used for the quadriceps and hamstrings, whereas smaller electrodes (4.5 x 4.5 cm) were used for the tibialis anterior and gastrocnemius. Electrode placement aimed to identify motor points capable of eliciting an effective functional muscle contraction while remaining within patient tolerance.

Stimulation was delivered in bilateral eight-channel mode using rectangular biphasic pulses at 30 Hz with a pulse width of 200 microseconds according to Cudia *et al.*¹⁹ Intensity was individualized and adjusted to elicit the minimum functional contraction tolerated by the patient, approximately between 30 and 70 mA. Stimulation intensity could be modified during a session and across sessions according to patient tolerance and the quality of the visible or palpable muscle contraction. Participants were seated in front of the cycle ergometer with their feet secured to the pedals, and both patient and therapist could monitor time, device functioning, and electrode activity through the display placed in front of the patient. The therapist supervised the session, device functioning, patient tolerance, and clinical status throughout treatment.

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Exploratory clinical outcomes

Clinical outcomes were assessed before and after the three-week intervention. Functional mobility was evaluated using the Timed Up and Go test, which is clinically relevant in ALS because slower performance has been associated with increased fall risk.²⁷ Walking speed was assessed using the 10-Meter Walk Test, which has been used alongside the 6MWT and TUG as an objective motor outcome in ambulatory ALS cohorts.²⁸ Walking endurance was assessed using the 6-Minute Walk Test, a practical measure of walking capacity in ambulatory individuals with ALS.²⁸ These outcomes were considered exploratory functional indicators because they are related to mobility and walking capacity but cannot establish treatment efficacy in the absence of a comparator.

Lower-limb muscle strength was assessed bilaterally using the Medical Research Council scale, which has documented reliability and validity for clinical strength testing.²⁹ Lower-limb spasticity was assessed using the Modified Ashworth Scale, a widely used clinical scale for spasticity assessment.³⁰ Strength and spasticity outcomes were interpreted descriptively and cautiously because ordinal scales and multiple muscle-level comparisons may inflate apparent findings in small samples.

Statistical analysis

Descriptive statistics were used to summarize baseline characteristics, feasibility outcomes, apparent safety outcomes, and clinical variables. Continuous outcomes were reported as mean and standard deviation. Pre-post comparisons were performed using paired tests according to data distribution. The Shapiro-Wilk test was used to assess normality. Paired Student t tests or Wilcoxon signed-rank tests were applied as appropriate. Statistical significance was set at $p < 0.05$.

Given the pilot feasibility design, the absence of a control group, and the small sample size, p values were interpreted as exploratory only. No adjustment for multiplicity was performed. The statistical analysis was used to describe within-group change and to inform future sample-size and design considerations, not to demonstrate efficacy.

Results

Participant characteristics

Fifteen patients were assessed for possible participation in FES-cycling during the recruitment period. Eleven patients were enrolled, corresponding to an enrollment proportion of 73.3% among assessed candidates. The enrolled cohort included five patients with ALS and six patients with PLS. The enrolled sample included seven men and four women. Mean age was 59.5 years, and mean time from

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diagnosis was 4.5 years. All enrolled participants met the inclusion criteria, were able to perform the required clinical assessments, and entered the planned three-week FES-cycling programme. Baseline characteristics are presented in Table 1.

Feasibility and apparent safety outcomes

All enrolled participants completed the planned intervention, corresponding to a completion rate of 100% among enrolled patients. No participant discontinued the protocol because of intolerance, excessive fatigue, pain, device-related problems, or clinical deterioration during the intervention period. Fatigue and discomfort monitoring was based on therapist clinical observation and patient feedback; no standardized fatigue or discomfort scale was used. No adverse events were documented during treatment sessions or assessment procedures. These findings indicate that the protocol was deliverable in this selected inpatient sample of ambulatory patients with ALS or PLS. The available source data provided a complete recruitment denominator (11/15; 73.3%) and a completion rate among enrolled participants (11/11; 100%). Feasibility and apparent safety outcomes are shown in Table 2.

Exploratory functional outcomes

Exploratory pre-post analyses showed favourable changes in all three functional measures. Timed Up and Go performance improved from 49.75 (34.31) seconds before treatment to 37.90 (25.69) seconds after treatment, with a mean within-group change of 11.85 (8.62) seconds ($p=0.003$). The 10-Meter Walk Test improved from 34.75 (22.34) seconds to 28.91 (18.91) seconds, with a mean change of 5.84 (3.43) seconds ($p=0.003$). The 6-Minute Walk Test improved from 123.27 (69.39) meters to 146.64 (75.98) meters, with a mean change of 23.37 (6.59) meters ($p<0.001$).

These findings suggest favourable short-term functional signals in mobility, walking speed, and walking endurance. However, because all patients also received conventional neuromotor rehabilitation and no control group was included, the observed changes cannot be attributed specifically to FES-cycling. Exploratory functional outcomes are reported in Table 3.

Exploratory strength and spasticity outcomes

Lower-limb muscle strength remained stable or improved across the assessed muscle groups. No deterioration was observed in the muscle groups assessed using the Medical Research Council scale. Improvements were reported bilaterally for iliopsoas, quadriceps, hamstrings, tibialis anterior, triceps surae, and peroneal muscles.

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Spasticity, assessed using the Modified Ashworth Scale, also showed stable or favourable values after treatment. Total Modified Ashworth Scale scores improved on both sides, whereas some individual joint-level measures, particularly hip flexion and left ankle dorsiflexion, showed no statistically significant change. These findings should be interpreted cautiously because of the ordinal nature of the scales, the small sample, and the number of comparisons.

Discussion

Main findings

This single-arm longitudinal pilot feasibility study examined a short FES-cycling protocol in ambulatory patients with ALS or PLS during inpatient neurorehabilitation. The main finding is that the intervention was deliverable and apparently safe in this selected sample: all participants completed the planned 15-session programme, no adverse events were documented, and complete pre-post clinical data were available. These results support the feasibility of delivering FES-cycling in clinically eligible patients with motor neuron disease within a supervised rehabilitation setting.

The second finding is that exploratory clinical outcomes moved in a favourable direction after the intervention period. Functional mobility, walking speed, walking endurance, lower-limb strength, and spasticity showed stable or improved values. These changes are clinically relevant because maintaining walking capacity and mobility is a central rehabilitation goal in ALS and PLS. However, the design does not allow causal interpretation. The observed changes may reflect FES-cycling, conventional rehabilitation, repeated testing, short-term inpatient care, selection of clinically stable patients, or a combination of these factors.

Comparison with ALS and PLS rehabilitation literature

The present results are consistent with the cautious direction of the ALS exercise literature. The Cochrane review reported limited randomized evidence but did not identify exercise-related adverse events in the available trials.⁸ Clawson and colleagues later showed that range-of-motion, resistance, and endurance regimens were tolerated over 24 weeks without worsening ALS functional outcomes, with better compliance in resistance and range-of-motion groups.⁹ Merico and colleagues, in a pilot randomized controlled study, reported that combined endurance and resistance training was beneficial and may counteract deconditioning and disuse-related atrophy in selected patients with ALS.¹⁰ More recent reviews have reinforced the concept that tailored, moderate physical exercise may be a useful

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co-adjuvant strategy, while also emphasizing heterogeneity, patient selection, fatigue monitoring, and disease-stage considerations.¹¹

The present study differs from those exercise studies because the intervention was technology-assisted and combined motorized cycling with phase-synchronized electrical stimulation. Therefore, its findings should not be interpreted as another exercise-efficacy result. Instead, they add feasibility information on whether a selected ALS/PLS inpatient population can tolerate and complete this specific modality. This distinction is aligned with the European Academy of Neurology guideline, which places rehabilitation within multidisciplinary symptom management rather than as a disease-modifying therapy.³ For PLS, evidence on physiotherapy and exercise remains even more limited; recent overviews underline the lack of disease-specific experimental rehabilitation data and the need for monitored approaches addressing spasticity, mobility, and function.⁵ The inclusion of PLS patients therefore increases clinical relevance but also adds heterogeneity that should be handled prospectively in future studies.

Comparison with FES-cycling and electrical stimulation literature

Compared with other neurological populations, the evidence base for FES-cycling in ALS and PLS remains sparse. In stroke, Ambrosini and colleagues reported that cycling induced by electrical stimulation improved motor recovery in post-acute hemiparetic patients, whereas Bauer and colleagues described therapeutic effects of FES-assisted active cycling in subacute hemiparesis.^{13,14} In multiple sclerosis, Ratchford and colleagues reported feasibility and encouraging functional signals in progressive disease, and Backus and colleagues reported outcomes after FES-cycle training in nonambulatory individuals.^{15,16} In spinal cord injury, lower-limb FES-cycling has been linked to physical and functional recovery, and a later systematic review concluded that FES-cycling may improve lower-body muscle health and fitness-related outcomes.^{17,18} In myotonic dystrophy type 1, Cudia and colleagues reported a pilot controlled study showing that lower-extremity FES training could be clinically meaningful in a neuromuscular disease population.¹⁹

These studies provide useful external plausibility but cannot be generalized directly to ALS and PLS. Stroke and spinal cord injury are primarily non-progressive or post-lesional conditions in which training may exploit recovery or compensation mechanisms that differ from progressive motor neuron degeneration.^{13,14,17,18} Multiple sclerosis has fluctuating and inflammatory components, and myotonic dystrophy has a different myopathic pathophysiology.^{15,16,19} In ALS and PLS, tolerance, fatigue, respiratory reserve, denervation, and progression create a narrower safety margin. The closest historical

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ALS-specific electrical stimulation evidence is the single-patient therapeutic electrical stimulation report by Handa and colleagues.²² The present study therefore fills a small but important gap by reporting feasibility and apparent safety of a structured FES-cycling protocol in a motor neuron disease cohort, rather than extrapolating exclusively from other diagnoses.

Mechanistic and translational interpretation

FES-cycling may be attractive in motor neuron disease because it combines several therapeutic components: cyclic lower-limb movement, electrical activation of selected muscles, sensory afferent input, cardiovascular exercise, and therapist-supervised task repetition. Experimental work in superoxide dismutase 1 (SOD1)-related ALS models suggests that skeletal muscle may be involved in disease mechanisms beyond passive denervation.^{20,21} However, this does not imply that FES-cycling modifies ALS pathogenesis. In the present study, the rationale was functional and rehabilitative rather than disease-modifying: the intervention was intended to explore feasibility, tolerance, and short-term functional signals in selected ambulatory patients.

The favourable changes in TUG, 10MWT, and 6MWT are compatible with improved short-term functional performance, but they are not specific enough to identify mechanisms. A shorter TUG time may reflect improved transfer ability, turning, walking speed, confidence, or reduced spasticity. A better 10MWT may reflect walking speed or step efficiency. A higher 6MWT distance may reflect endurance, pacing, motivation, or reduced fatigue during assessment. Future studies should add instrumental gait analysis, wearable monitoring, surface electromyography, dynamometry, fatigue scales, respiratory measures, and patient-reported outcomes to clarify whether the intervention affects muscle activation, movement quality, endurance, perceived effort, or daily mobility.

Feasibility interpretation and implications for future research

The main strength of the current framing is the explicit separation between feasibility outcomes and exploratory clinical outcomes. The availability of the total number of assessed candidates provided a complete recruitment denominator for the treated feasibility cohort, with 11 of 15 assessed patients enrolled. Completion rate, absence of documented adverse events and complete outcome data support progression toward a more rigorous prospective study. However, several feasibility domains were not prospectively measured, including detailed reasons for non-participation, standardized acceptability, intervention fidelity, therapist workload, quantified fatigue response, standardized respiratory outcomes, and longer-term retention.

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A future study should therefore be a prospective controlled feasibility trial before a definitive efficacy trial is attempted. A suitable design would compare conventional rehabilitation alone with conventional rehabilitation plus FES-cycling, using matched treatment dose across groups, including session number, session duration, therapist contact time, and total rehabilitation exposure. Feasibility outcomes should remain the primary endpoint, with clinical outcomes as secondary exploratory endpoints. Progression criteria should be defined a priori for recruitment, completion, safety, data completeness, and acceptability before a definitive efficacy trial is attempted. Later efficacy trials would require allocation concealment, blinded outcome assessment, standardized adverse-event reporting, intervention-fidelity monitoring, follow-up assessment, and sample-size calculation based on clinically meaningful endpoints.

Limitations

Several limitations should be acknowledged. First, this was a single-arm study without a control group. Therefore, the observed clinical changes cannot be attributed specifically to FES-cycling and should not be interpreted as evidence of efficacy. Second, the sample was small and included only patients able to perform walking assessments and complete the intervention, limiting generalizability to more advanced disease stages. Third, the intervention was delivered together with conventional neuromotor rehabilitation, preventing separation of treatment effects.

Fourth, feasibility was not planned prospectively using predefined progression criteria. Although the total number of assessed candidates was available, detailed screening logs, reasons for non-enrollment, formal fidelity assessment, standardized acceptability questionnaires, quantified fatigue response, therapist burden, and retention were not systematically collected. Fatigue and discomfort were monitored clinically, but no standardized scale was used. Fifth, there was no follow-up assessment, so persistence of any functional change is unknown. Sixth, clinical outcomes were based mainly on functional tests and ordinal clinical scales, without instrumental assessment of gait quality, muscle activation, spasticity, respiratory status, or fatigue. The absence of ALSFRS-R limits interpretation of disease-stage stability and global functional progression during the intervention period. Although the diagnostic distribution was available (five patients with ALS and six with PLS), subgroup-specific outcomes could not be reported because of the very small sample size; future clinical studies should report baseline characteristics and outcomes separately by disease type. Finally, multiple exploratory comparisons were performed in a very small sample, increasing the risk of overinterpretation.

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Conclusions

This single-arm longitudinal pilot feasibility study suggests that a short FES-cycling protocol is feasible and apparently safe in selected ambulatory patients with ALS or PLS during inpatient neurorehabilitation. All participants completed the intervention, no adverse events were documented, and complete pre-post clinical data were available. Exploratory outcomes showed favourable short-term changes in functional mobility, walking speed, walking endurance, strength, and spasticity. These findings should be interpreted as feasibility and hypothesis-generating data, not as confirmatory evidence of efficacy. The study supports the development of a prospective controlled feasibility trial with predefined progression criteria, standardized safety and acceptability monitoring, follow-up assessment, and more sensitive instrumental outcomes to determine whether FES-cycling provides clinically meaningful benefit beyond conventional rehabilitation.

List of Abbreviations

ALS, amyotrophic lateral sclerosis; FES, functional electrical stimulation; FES-cycling, functional electrical stimulation-assisted cycling; MAS, Modified Ashworth Scale; MMSE, Mini-Mental State Examination; MRC, Medical Research Council; PLS, primary lateral sclerosis; TUG, Timed Up and Go; 6MWT, 6-Minute Walk Test; 10MWT, 10-Meter Walk Test.

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Contributions

Martina Regazzetti contributed to conceptualization, methodology, data curation, formal analysis, and writing – original draft. Pawel Kiper contributed to methodology, supervision, and writing – review and editing. Antonio Merico contributed to methodology, data curation, and writing – review and editing. Simonetta Rossi contributed to investigation, resources, and writing – review and editing. Diego Bulcão Visco contributed to supervision, project administration, and writing – review and editing. Carlos Luque Moreno contributed to supervision, project administration, and writing – review and editing. Alfons Baba contributed to conceptualization, methodology, supervision, and writing – review and editing. All authors critically revised the manuscript, approved the final version, and agreed to be accountable for all aspects of the work.

Conflict of interest

The authors declare no commercial or financial relationships that could be viewed as a potential conflict of interest.

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Ethics approval and consent to participate

As described on page 303 of the 2010–2012 Clinical and Scientific Activity Report of IRCCS San Camillo Hospital, Venice, p.303 (2010-2012). All participants were informed about the clinical assessment and treatment procedures and provided informed consent.

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Artificial intelligence-assisted technologies

AI-assisted technologies were used to support language editing, formatting, reference-style checking, and figure/infographic preparation. All scientific content, interpretation of the data, references, and

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final manuscript text were reviewed, edited, and approved by the authors, who take full responsibility for the integrity, originality, and accuracy of the submitted work.

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Table 1. Baseline characteristics of the included participants.

Characteristic	Value
Patients assessed for eligibility, n	15
Enrolled participants, n (%)	11/15 (73.3%)
Sex, men/women, n	7/4
Age, years, mean (SD)	59.5 (13.8)
Time from diagnosis, years, mean (SD)	4.5 (4.5)
Men: age, years, mean (SD)	64.1 (10.0)
Men: time from diagnosis, years, mean (SD)	4.8 (4.7)
Women: age, years, mean (SD)	51.5 (17.4)
Women: time from diagnosis, years, mean (SD)	5.0 (4.9)
Diagnosis	ALS, n = 5; PLS, n = 6
Amyotrophic lateral sclerosis, n	5
Primary lateral sclerosis, n	6

ALS, amyotrophic lateral sclerosis; PLS, primary lateral sclerosis; SD, standard deviation.

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Table 2. Feasibility and apparent safety outcomes.

Feasibility/apparent safety domain	Observed result
Eligibility/enrollment	11/15 assessed patients enrolled (73.3%); recruitment denominator complete.
Intervention completion	11/11 enrolled participants completed the planned 15-session protocol.
Treatment tolerance	No discontinuation due to intolerance, excessive fatigue, pain, device-related problems, or clinical deterioration.
Fatigue/discomfort monitoring	Monitored through therapist clinical observation and patient feedback; no standardized fatigue or discomfort scale was used.
Stimulation intensity adjustment	Individualized at approximately 30–70 mA and modifiable during or between sessions according to tolerance and muscle contraction quality.
Apparent safety	No adverse events were documented during assessment or treatment.
Data completeness	Complete pre-post clinical outcome data were available for all enrolled participants.

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Table 3. Exploratory functional outcomes before and after the intervention.

Outcome	Pre, mean (SD)	Post, mean (SD)	Mean change (SD)	Descriptive exploratory p value
Timed Up and Go, seconds	49.75 (34.31)	37.90 (25.69)	11.85 (8.62)	0.003
10-Meter Walk Test, seconds	34.75 (22.34)	28.91 (18.91)	5.84 (3.43)	0.003
6-Minute Walk Test, meters	123.27 (69.39)	146.64 (75.98)	23.37 (6.59)	<0.001

SD, standard deviation. P values are descriptive and exploratory and should not be interpreted as confirmatory evidence of efficacy because no control group was included.