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Exercise for Patients with Neuromuscular Diseases

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Neuromuscular diseases (NMDs) comprise a heterogeneous spectrum of inherited and acquired disorders affecting anterior horn cells, peripheral nerves, neuromuscular junctions, or skeletal muscle, resulting in progressive weakness, fatigue, and functional decline. Historically, exercise was discouraged due to concerns of "overuse weakness"; however, a growing body of evidence now supports the safety and efficacy of supervised submaximal exercise as a therapeutic intervention for various NMD subtypes. Moderate-intensity aerobic and strength training improves mitochondrial biogenesis, oxidative efficiency, and preserves neuromuscular integrity through activation of the AMPK–SIRT1–PGC-1α and mTORC1–Akt signaling pathways, while promoting antioxidant and anti-inflammatory responses. Individualized exercise programs tailored to the functional status of patients and adapted to the specific metabolic and structural characteristics of certain neuromuscular diseases improve endurance, muscle strength, and quality of life without accelerating disease progression. In the era of disease-modifying therapies, the role of exercise as a complementary measure to enhance therapeutic efficacy is gaining increasing scientific and clinical importance. A multimodal, individualized approach integrating aerobic exercise, strength training, flexibility training, respiratory training, and computer-assisted interventions under clinical supervision represents the current standard of care.

Key words: Neuromuscular disease, Therapeutic exercise, Aerobic training, Resistance training

REVIEW ARTICLE

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INTRODUCTION

Neuromuscular diseases (NMDs) represent a diverse group of inherited and acquired disorders affecting anterior horn cells, peripheral nerves, neuromuscular junctions, or skeletal muscle fibers. Despite their diverse etiologies, these disorders share common features, including progressive muscle weakness, fatigue, contractures, and loss of functional autonomy, which significantly impair quality of life and increase the burden of care. Historically, exercise was viewed with caution in this population. Since the mid-20th century, clinicians have warned of the risk of irreversible damage caused by voluntary muscle contraction, a notion termed "overuse weakness" [1,2]. Consequently, rest and immobility were often prescribed, which paradoxically exacerbated deconditioning, cardiorespiratory decline, and secondary complications such as contractures and osteoporosis.

A paradigm shift occurred in the late 20th century when controlled studies challenged this traditional view. Early research showed that supervised submaximal exercise could improve strength and endurance without accelerating disease progression [3,4]. Subsequent randomized controlled trials (RCTs) in various neuromuscular conditions, including Duchenne muscular dystrophy (DMD), spinal muscular atrophy (SMA), mitochondrial myopathies, and amyotrophic lateral sclerosis (ALS), have confirmed that appropriately dosed training is both safe and beneficial [5-7]. These results overturned previous dogma by establishing a crucial distinction between therapeutic activation and pathological overuse. The principle of "training without exhaustion" has now become a central tenet of

modern neuromuscular rehabilitation.

At the molecular level, exercise activates adaptive pathways that improve cellular resilience. Aerobic activity upregulates the AMPK–PGC-1α axis, promoting mitochondrial biogenesis, oxidative phosphorylation, and fatigue resistance [8-10]. Moderate resistance training stimulates mTORC1-mediated protein synthesis, facilitating myofibrillar repair without oxidative injury [11]. Furthermore, exercise modulates inflammation and redox homeostasis by reducing pro-inflammatory cytokines (TNF-α, IL-6) and increasing the expression of antioxidant enzymes [12]. These findings redefine exercise as a biologically active therapy that can shift muscle metabolism from a catabolic to an anabolic balance.

Despite the growing body of evidence, implementation in clinical practice remains inconsistent. Variations in study design, training intensity, and safety monitoring have led to heterogeneous results, leaving clinicians uncertain about optimal prescriptions. Therefore, this review aims to synthesize current evidence on the role of exercise in neuromuscular diseases, presenting disease-specific recommendations from clinical studies, the efficacy and safety of key exercise modalities, and the prospects for integrating digital health and precision rehabilitation into clinical care.

DISEASE-SPECIFIC EXERCISE RECOMMENDATIONS

Neuromuscular diseases differ in pathophysiology, disease trajectory, and residual motor potential; thus, exercise prescription must be individualized. A growing body of RCTs and cohort studies demonstrates that carefully done, submaximal programs improve performance and quality of life without accelerating muscle degeneration.

Amyotrophic lateral sclerosis

In ALS, progressive degeneration of motor neurons leads to general weakness and difficulty breathing. Moderate-intensity aerobic and resistance training (40%–60% of VO_2max; rating of perceived exertion [RPE] ≤ 13) has been shown to improve motor performance and attenuate the rate of functional decline [13,14]. Dal Bello-Haas et al. [13] showed significant improvements in Amyotrophic Lateral Sclerosis Functional Rating Scale–Revised (ALSFRS-R) scores after a 12-week combined training program. Exercise intensity exceeding 70% of the individual's maximum heart rate (HRmax) or the presence of post-exercise muscle soreness persisting for more than 24 hours should be considered an indicator for temporary exercise cessation. Periodic assessment of serum creatine kinase (CK) levels and forced vital capacity (FVC) is recommended to monitor for subclinical muscle injury and evolving respiratory compromise.

Duchenne muscular dystrophy

Dystrophin deficiency increases the susceptibility of muscle fibers to eccentric loading. Accordingly, safe exercise modalities for patients with DMD include gentle concentric or aquatic activities performed at intensities ≤ 40% of VO_2max, two to three times per week [15,16]. Aquatic therapy has been shown to improve endurance and postural control without increasing serum CK levels. However, eccentric exercises and high-resistance training are contraindicated due to the risk of muscle fiber damage.

Spinal muscular atrophy

Residual motor neurons retain the capacity for compensatory hypertrophy in response to low-load progressive resistance training [17]. Abresch et al. [18] reported improvements in posture and respiratory function after 8–12 weeks of training with ≤ 50% of the one-repetition maximum (1RM) combined with daily inspiratory muscle training. Training programs should include careful monitoring of fatigue and appropriate respiratory support to ensure safety and optimize functional outcomes.

With the advent of disease-modifying therapies such as *nusinersen*, *onasemnogene abeparvovec*, and *risdiplam*, rehabilitation and exercise interventions have gained importance as complementary strategies to optimize functional recovery and maintain motor performance in patients with SMA [19].

Mitochondrial myopathies

Aerobic deficits are prominent in patients with mitochondrial myopathies; therefore, structured aerobic exercise may enhance oxidative enzyme activity and attenuate lactate accumulation [10,20]. Tarnopolsky and Halonen demonstrated significant improvements in peak VO_2 after submaximal cycling performed at 50%–70% of VO_2max for 20–30 minutes per session. High-intensity interval training should be avoided to reduce the risk of metabolic crises.

Inflammatory myopathies

During phases of inactivity or remission, low-load circuit or flexibility training may improve endurance and quality of life

without increasing serum CK levels [21,22]. In case of active inflammation or feverish illness, training should be discontinued. Regular CK monitoring and medical supervision remain essential to ensure safety and prevent worsening of disease activity.

Slowly progressive NMDs

Combined aerobic-strength training protocols have demonstrated synergistic benefits in patients with slowly progressive neuromuscular disorders. Programs incorporating submaximal cycling at approximately 60% of HRmax for 12 weeks have demonstrated an increase in aerobic capacity of approximately 15% and maintenance of performance in activities of daily living (ADL) and fatigue tolerance, particularly in cases of myotonic dystrophy or facioscapulohumeral muscular dystrophy [23-25]. The integration of moderate resistance exercises, targeting major proximal and antigravity muscle groups, further promotes muscular endurance and functional stability without inducing myofibrillar damage or excessive elevations in serum CK.

EXERCISE MODALITIES AND IMPLEMENTATION STRATEGIES

The clinical effectiveness of exercise in NMDs is determined not only by the total workload but also by the type, intensity, and context of the intervention. Each exercise modality engages distinct but interdependent physiological systems—metabolic, neuromuscular, cardiopulmonary, and neuroplastic—that collectively contribute to adaptive remodeling and functional resilience. Therefore, a multimodal exercise model integrating aerobic, strength, flexibility, breathing, and task-oriented functional training, with or without digital monitoring and feedback, is considered the optimal therapeutic approach.

Aerobic training

Aerobic exercise remains the cornerstone of metabolic conditioning in patients with neurodegenerative diseases. Through activation of the AMPK–SIRT1–PGC-1α signaling cascade, it enhances mitochondrial biogenesis, upregulates oxidative enzyme activity, and optimizes substrate utilization, thereby increasing cellular energy metabolism and fatigue resistance [8,9]. The physiological benefits of aerobic exercise include increased endurance, reduced lactate accumulation, and improved resistance to fatigue.

Clinical trials in patients with mitochondrial myopathies, ALS, and muscular dystrophies have demonstrated significant improvements in VO_2 max, six-minute walk distance, and perceived exertion after 8 to 12 weeks of moderate-intensity training (40%–70% of VO_2max; RPE≤13; 20–30 minutes per session, two to four times per week) [7,17,20]. Regular monitoring of heart rate and serum CK levels is essential to ensure safety and prevent overexertion. For individuals with joint or respiratory limitations, supervised aquatic exercise or cycle ergometers are safe and effective alternatives for maintaining aerobic capacity.

Resistance training

Resistance training promotes muscular strength and endurance primarily through activation of the mTORC1 and IGF-1–Akt signaling pathways, while simultaneously suppressing catabolic processes [3,26]. Low- to moderate-intensity loading (≤50% of 1RM, 10–15 repetitions, two to three sessions per week) has been shown to preserve myofibrillar integrity and prevent sarcolemmal rupture. High-resistance eccentric exercises should be avoided, and alternating rest intervals are recommended to minimize the risk of overuse injury and delayed recovery [13].

Flexibility and stretching training

Flexibility exercises play an important role in the prevention of joint contractures, spasticity, and postural deformities by maintaining soft tissue extensibility, joint mobility, and optimal flexibility of muscles and tendons [27]. Regular stretching also improves blood flow to the periarticular tissue and promotes proprioceptive feedback, contributing to greater comfort and less pain. A daily practice of gentle, sustained stretching—usually 10 to 30 seconds per muscle group, repeated two to three times—is recommended to maintain range of motion and relieve stiffness [28].

Excessive stretching should be avoided, especially in cases of active inflammation or fibrotic progression, as excessive tension can exacerbate microtrauma and inflammatory reactions. Wearing orthoses or positioning aids can promote correct joint alignment and prevent the development of contractures in patients with severe muscle weakness or impaired voluntary control. When performed regularly under clinical supervision, flexibility training is an essential component of comprehensive neuromuscular rehabilitation, complementing aerobic and resistance exercises to maintain functional mobility and comfort.

Respiratory muscle training

Respiratory muscle training, particularly with a focus on strengthening the inspiratory muscles, is an important complementary measure for maintaining ventilation function and airway clearance in patients with neuromuscular diseases [29,30]. Targeted training of the inspiratory muscles improves diaphragmatic contractility, promotes chest expansion, and increases cough efficiency, thereby limiting the progression of hypoventilation and recurrent respiratory infections. Daily inspiratory muscle training with a threshold load (approximately 15 to 20 minutes per day) has been shown to improve inspiratory muscle strength (e.g., maximum inspiratory pressure [MIP]) and cough efficiency, and may help stabilize or modestly improve lung function in certain patient cohorts [30]. Evidence suggesting that this intervention delays ventilator dependence remains preliminary, particularly in ALS and DMD [31-33].

Aquatic therapy

Aquatic therapy provides a supportive, low-impact environment that facilitates movement for patients with NMDs. The buoyancy of the water counteracts gravity, reducing the mechanical load on weight-bearing joints and allowing patients with muscle weakness or pain to perform functional movements with less effort and discomfort. At the same time, hydrostatic pressure improves venous return, reduces peripheral edema and promotes proprioceptive signals, contributing to better postural control and overall cardiovascular performance.

Therapeutic sessions in thermoneutral water (approximately 30–32°C) promote muscle relaxation, reduce spasticity, and enable smooth, coordinated movements. Regular hydrotherapy has been proven to improve endurance, flexibility, and subjective well-being through its combined effects on circulation, neuromuscular activation, and psychological relaxation [15,16].

Hind et al. [34] reported significant improvements in balance, walking stability, and aerobic capacity in children with DMD following a structured aquatic exercise program. These findings underscore the benefit of aquatic environments for maintaining function in children with progressive muscle weakness.

Therapist supervision is essential to ensure proper technique, intensity control, and safety, particularly in individuals with respiratory difficulties or those prone to fatigue. Exercise intensity should be increased gradually, with an emphasis on continuous rather than ballistic movements. Perceived exertion, heart rate, and post-session fatigue should be carefully monitored. The integration of buoyancy aids and shallow-water equipment allows for greater treatment personalization and expands opportunities for safe participation, regardless of disease stage.

Table 1 provides an overview of the main exercise modalities used in the rehabilitation of NMDs, describing their underlying physiological rationale and key clinical considerations for safe and effective implementation.

Each modality offers distinct physiological benefits: aerobic and strength training improve endurance and strength; stretch-

Table 1. Summary of exercise modalities, physiological rationale, and clinical considerations in the rehabilitation of neuromuscular diseases

Exercise Modality	Physiological rationale/ primary mechanism	Recommended parameters	Clinical considerations
Aerobic Training	Enhances mitochondrial biogenesis via AMPK–SIRT1–PGC-1α axis; increases oxidative enzyme activity and fatigue resistance	40%–70% VO_2max, RPE≤13, 20–30 min/session, 2–4×/week	Monitor HR & CK; avoid >70% HRmax; aquatic or cycling modes for joint/respiratory limitation
Resistance Training	Activates mTORC1–IGF-1–Akt pathway; improves muscle protein synthesis and strength	≤50% 1RM, 10–15 reps, 2–3×/week	Alternate-day sessions; avoid high-resistance eccentric work; combined with stretching
Flexibility/Stretching	Maintains joint mobility and muscle-tendon compliance; reduces contracture, spasticity	Gentle static stretch 10–30 sec, 2–3 reps/muscle, daily	Avoid overstretching during inflammation/fibrosis; use orthotics for positioning
Respiratory Muscle Training (IMT)	Strengthens diaphragm and accessory inspiratory muscles; activates AMPK–PGC-1α to improve endurance	30%–60% MIP, 15–20 min/day, 5–7 days/week	Monitor SpO_2 & symptoms; discontinue if desaturation <90% or severe fatigue; combine with NIV or MI-E if needed
Aquatic/ Hydrotherapy	Buoyancy & hydrostatic pressure reduce mechanical load, enhance proprioception and venous return	30–32 °C water, 20–40 min/session, 2–3×/week	Supervised sessions; gradual intensity progression; caution in severe respiratory or cardiac dysfunction

VO_2max, maximal oxygen uptake; RPE, rating of perceived exertion; HR, heart rate; HRmax, maximal heart rate; CK, creatine kinase; 1RM, one-repetition maximum; MIP, maximal inspiratory pressure; SpO_2, peripheral oxygen saturation; NIV, non-invasive ventilation; MI-E, mechanical insufflation-exsufflation.

ing preserves joint range of motion; and respiratory and aquatic therapy promotes cardiopulmonary and postural health. Combined multimodal programs provide maximum benefit in individualized, supervised programs.

CONCLUSION

Physical exercise was once contraindicated but is now an essential, evidence-based therapeutic modality in the treatment of NMDs. A growing body of research demonstrates that submaximal exercise prescription, carefully individualized based on disease progression and each patient's functional status, results in clinically meaningful improvements in endurance, metabolic efficiency, and psychosocial well-being, without accelerating muscle degeneration.

Individualized exercise prescription is therefore fundamental to the rehabilitation of NMDs. Given the heterogeneity of disease trajectories and residual motor capacity, aerobic, strength, flexibility, and respiratory training must be tailored in terms of frequency, intensity, and modalities. Such patient-specific programming maximizes therapeutic efficacy while minimizing the risks of overwork weakness and fatigue.

In summary, physical exercise is now recognized as a cornerstone of comprehensive neuromuscular rehabilitation and no longer as a complementary intervention. When delivered at submaximal intensity, guided by physiological monitoring, and supervised by skilled clinicians, it enhances motor performance, delays functional decline, and improves quality of life. Future directions should emphasize the harmonization of international guidelines, establishment of standardized safety and intensity parameters, and validation of digital biomarkers to realize precision, adaptive rehabilitation across the spectrum of neuromuscular diseases.

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