



## Review Article

**Cite this article:** Marconi S, Gilberti G, Zanini B, Marullo M, Montani G, Risi B, Padovani A, Castellano M, and Filosto M (2026). Diet and nutrition in patients with neuromuscular disorders, as lifestyle factors affecting clinical parameters and quality of life: a narrative systematic review. *Nutrition Research Reviews* 39: e21, 1–14. doi: [10.1017/S0954422426100420](https://doi.org/10.1017/S0954422426100420)

Received: 29 March 2025

Revised: 10 April 2026

Accepted: 15 April 2026


**Keywords:**

diet; emotional perception and care; lifestyle; neuromuscular disorders; physical activity; quality of life

**Corresponding author:**

Silvia Marconi; Email: [silvia.marconi@unibs.it](mailto:silvia.marconi@unibs.it)

# Diet and nutrition in patients with neuromuscular disorders, as lifestyle factors affecting clinical parameters and quality of life: a narrative systematic review

Silvia Marconi<sup>1</sup> , Giulia Gilberti<sup>1,2</sup>, Barbara Zanini<sup>1</sup>, Monica Marullo<sup>1</sup>, Giacomo Montani<sup>3</sup>, Barbara Risi<sup>2</sup>, Alessandro Padovani<sup>1,4</sup>, Maurizio Castellano<sup>1</sup> and Massimiliano Filosto<sup>1,2</sup>

<sup>1</sup>Department of Clinical and Experimental Sciences, University of Brescia, Brescia, Italy; <sup>2</sup>NeMO Clinical Center for Neuromuscular Diseases, Brescia, Italy; <sup>3</sup>Dietetics and Clinical Nutrition Service, ASST Spedali Civili di Brescia, Brescia, Italy and <sup>4</sup>Unit of Neurology, ERN EURO-NMD Center, ASST Spedali Civili di Brescia, Brescia, Italy

**Abstract**

Neuromuscular disorders (NMDs) are a heterogeneous group of conditions characterised by progressive muscle weakness, motor impairment, and risk of malnutrition, affecting the quality of life (QoL) of patients. While pharmacological treatments are essential for the management of symptoms, the role of diet, nutrition, and other lifestyle factors remains underexplored. This narrative systematic review, performed on PubMed, Web of Science, and Scopus following PRISMA guidelines, aimed to investigate the relationship between lifestyle, the progression of NMDs, and the QoL. A total of 30 studies ( $n = 5055$  patients) met inclusion criteria. According to our search strategy, the most representative lifestyle factors were diet (70%), physical activity (53.3%), and emotional perception and care (36.7%); seven papers (23.3%) evaluated three or more lifestyle aspects. Overall, both quantitative and qualitative deficiencies emerged: calories, proteins, lipids, and fibres, as well as vitamin C, vitamin E, zinc, selenium, and calcium, were lower than recommended. A reduced consumption of fruits, vegetables, legumes, nuts, and seeds, replaced by ultra-processed foods, was detected. Diets optimised for calorie and nutrients intake, rich in anti-inflammatory foods, have shown benefits both in mitigating oxidative stress and muscle degeneration. Regarding other aspects of lifestyle, although physical activity was associated with improved motor performance and QoL, adherence was low, particularly among females. Negative emotional status emerged as a critical factor influencing patients' overall well-being. Even in the most complex neuromuscular disease settings, addressing nutrition and dietary habits, in the context of lifestyle, could support patients and their families throughout the disease course and improve their QoL.

**Introduction**

Individuals affected by neuromuscular diseases (NMDs) represent a clinically heterogeneous population with hereditary or acquired disorders involving muscles, neuromuscular junctions, peripheral nerves, or lower motor neurons. The predominant and common symptoms are muscle weakness and atrophy, fatigue, and pain. In addition, dysphagia, dysarthria, respiratory disorders, and multisystem involvement (i.e., gastrointestinal and cardiovascular system, liver and central nervous system) may be associated<sup>(1)</sup>. These factors significantly and progressively affect the mobility and autonomy of NMD patients, and the quality of life of both patients and their family members/caregivers<sup>(2–4)</sup>.

NMD patients are at increased risk of malnutrition: undernutrition may arise from reduced appetite and subsequent decrease in food intake, leading to inadequate energy and macro-nutrient and/or micronutrient intake<sup>(5)</sup>. Conversely, some patients may experience over-nutrition due to excessive caloric intake (with or without micronutrient deficiency), developing overweight and obesity, which can even be promoted by physical impairment, reduced activity, and pharmacological treatments, such as steroid drugs<sup>(6)</sup>.

In this population, gastrointestinal disorders are frequently observed: constipation, gastroesophageal reflux disease, dysphagia, and delayed gastric emptying contribute to maintaining or even worsening an inappropriate nutritional status<sup>(7,8)</sup>.

Common pathophysiological mechanisms in NMDs may include chronic inflammation, increased oxidative stress, autophagy, and mitochondrial dysfunction, which contribute to progressive muscle atrophy, neural damage, and functional decline<sup>(9–11)</sup>.

© The Author(s), 2026. Published by Cambridge University Press on behalf of The Nutrition Society. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (<https://creativecommons.org/licenses/by/4.0/>), which permits unrestricted re-use, distribution and reproduction, provided the original article is properly cited.



Current therapy of most NMDs is mainly symptomatic, with analgesic and corticosteroid therapy supplementing motor rehabilitation courses; the assessment of how diet and lifestyle can affect the condition of these patients should not be overlooked. Despite extensive evidence on the role of lifestyle – defined as diet, physical activity, quality of personal and social relationships, sleep hygiene, and smoking and alcohol addictions – in the prevention and management of chronic diseases, there is still inconclusive literature assessing the potential effects of these factors on the clinical course and on the quality of life (QoL) of patients with NMDs<sup>(12–14)</sup>.

Few aspects of lifestyle have been studied in NMDs, and most of these were individual studies. Regarding physical activity, although the mobility of these patients varies greatly according to the type of NMD and the progression of the disease, monitoring and promoting physical activity can positively affect the overall clinical outcome<sup>(15,16)</sup>.

There are currently few works in which the role of diet in this pathological context has been evaluated; the Mediterranean diet is among the most studied beneficial dietary patterns. The Mediterranean diet, rich in vitamins, fibres, and phytochemicals, and low in sugars, salt, and ultra-processed foods, could provide valuable support in counteracting the oxidative and inflammatory damage associated with NMDs<sup>(17,18)</sup>.

The Mediterranean model is not only a dietary pattern, but encompasses many other aspects of lifestyle, such as daily physical activity, balance of daily activities and nightly rest, conviviality and care of social relationships. Sharing experience of meals, not only in terms of consumption but also of preparation, as well as the choice of seasonal and locally sourced foods, are distinctive factors of this model<sup>(18,19)</sup>.

The purpose of this systematic review is to evaluate the state of art of the recent scientific evidence on the role of diet and nutrition, with particular focus on the Mediterranean diet and lifestyle, in affecting the clinical course of NMDs and the QoL of these patients.

## Methods

This systematic review meets criteria of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)<sup>(20)</sup>.

### Eligibility criteria

We included cross-sectional, prospective, and retrospective cohort studies, as well as randomised and non-randomised clinical trials, investigating the relationship between lifestyle or diet and these neuromuscular conditions, published in the past five years in peer-reviewed scientific journals. We included articles published in the last five years to provide an updated overview of recent evidence, reflecting current clinical practice. Articles were excluded if they were not published in English, were preprints or unpublished, were preclinical studies (including *in vitro* or animal-model studies), reviews, systematic reviews, meta-analyses, brief communications, letters to the editor, case reports, case series, guidelines, or conference abstracts. Additionally, articles that did not evaluate any aspect of the patients' lifestyle, or those that did not provide a diagnosis of neuromuscular disease at baseline or follow-up, were excluded.

### Information sources and search strategy

An electronic search was conducted on 24 September 2024 to identify published articles that mentioned 'neuromuscular disorders', 'muscular dystrophy', 'peripheral neuropathy',

'myopathy', 'motor neuron disease', or 'myasthenia' in combination with 'diet', 'nutrition', 'lifestyle', or 'Mediterranean diet'. The following electronic databases were utilised, along with their respective search strings:

- PubMed: Title/Abstract: (('neuromuscular disorders'[Title/Abstract] OR 'muscular dystrophy'[Title/Abstract] OR 'peripheral neuropathy'[Title/Abstract] OR 'myopathy'[Title/Abstract] OR 'motor neuron disease'[Title/Abstract] OR 'myasthenia'[Title/Abstract]) AND (diet[Title/Abstract] OR nutrition[Title/Abstract] OR lifestyle[Title/Abstract] OR 'Mediterranean diet'[Title/Abstract])) AND (English[Language]).
- Web of Science: Title/Abstract: ((TI=((('neuromuscular disorder' OR 'muscular dystrophy' OR 'peripheral neuropathy' OR myopathy OR 'motor neuron disease' OR myasthenia) AND (diet OR nutrition OR lifestyle OR 'Mediterranean diet')))) OR AB=((('neuromuscular disorder' OR 'muscular dystrophy' OR 'peripheral neuropathy' OR myopathy OR 'motor neuron disease' OR myasthenia) AND (diet OR nutrition OR lifestyle OR 'Mediterranean diet')))) AND LA=(English).
- Scopus: Title/Abstract: (TITLE(('neuromuscular disorders' OR 'muscular dystrophy' OR 'peripheral neuropathy' OR myopathy OR 'motor neuron disease' OR myasthenia) AND (diet OR nutrition OR lifestyle OR 'Mediterranean diet')))) OR ABS(('neuromuscular disorders' OR 'muscular dystrophy' OR 'peripheral neuropathy' OR myopathy OR 'motor neuron disease' OR myasthenia) AND (diet OR nutrition OR lifestyle OR 'Mediterranean diet')))) AND LANGUAGE(English) AND PUBYEAR > 2019 AND (LIMIT-TO(EXACTKEYWORD, 'Humans')).

### Selection and data collection process

A team consisting of one researcher and one associate professor in nutrition science from the Department of Clinical and Experimental Sciences at the University of Brescia, Italy (SM, BZ), and a research fellow from the same department (GG), reviewed the abstracts of selected studies and independently evaluated articles according to the established inclusion criteria, removing duplicates. The team members, along with a master's student in dietetics from the University of Brescia (DC), collected and synthesised data by thoroughly reviewing each selected article. Neurological data were subsequently evaluated by an associate professor of neurology at the Department of Clinical and Experimental Sciences at the University of Brescia, an expert in the field of neuromuscular diseases (MF). Disagreements or uncertainties were resolved through group discussions. No automated tools or artificial intelligence resources were employed during this process.

### Data items

For each selected article, information regarding authorship, year of publication, journal, study period and location, World Health Organization (WHO) region, and study design were recorded in a purpose-built Excel sheet, organised in three sections. The first section of the database contains baseline data about patients, including their number and, where available, the number and type of control subjects, demographics (age, sex, ethnicity), education level, employment status, family situation (caregivers), specific diagnosis of neuromuscular disease and associated pharmacological

treatments, most affected body areas, movement limitations, comorbidities, and the use of additional medications and/or supplements. Information on gastrointestinal issues (e.g., vomiting, gastroesophageal reflux, dysphagia, bowel irregularities) and feeding methods (oral or artificial nutrition) was also included, along with weight, body mass index (BMI), body composition data (specifically lean mass and fat mass), and nutritional status and related assessment methods. The second section of the database includes information regarding diet, nutrition, and lifestyle aspects of patients with NMDs, as assessed by relevant questionnaires: in addition to dietary habits, we evaluated other lifestyle factors if addressed in the selected articles, such as physical activity, substance use (alcohol and smoking), emotional perception and care, and sleep quality. Data or investigations related to the microbiota were included, if available. Finally, the last section includes study duration, primary and secondary endpoints, interventions, QoL, changes in endpoints, and dropout rates. For missing or unclear data, 'not available-NA' was recorded.

### Synthesis methods

All collected data were summarised into six tables for ease of analysis. Table 1 describes the types of articles selected, the publication year, and the country in which the study was conducted. Demographic data of patients (number, age, sex, ethnicity, education level, and employment status) are summarised in Table 2, while clinical data (type of NMD, steroid treatment, supplements, feeding method, gastrointestinal problems, and comorbidities) and microbiota analysis are presented in Table 3. Table 4 includes anthropometric measurements (BMI or BMI z-score, waist circumference, body composition, malnutrition screening, and nutritional status). Lifestyle aspects are summarised in Table 5: the number of patients evaluated in relation to dietary habits and other different lifestyle aspects (physical activity, sleep quality, addictions, and emotional perception and care) are reported. Finally, Table 6 lists the individual studies included in the review, detailing the first author, publication year, country, study design, sample size, and lifestyle aspects investigated. Percentages were calculated based on the available data for each specific characteristic.

### Bias and certainty assessment

Given the considerable heterogeneity in study design, populations, and assessment tools, this review was conducted as a narrative systematic review with qualitative analysis of the results and narrative synthesis, in line with PRISMA-S and Cochrane recommendations.

Percentages were calculated based on the available data for each considered element. This article does not represent a meta-analysis; therefore, as per the latest PRISMA guidelines<sup>(20)</sup>, no models were applied to assess statistical heterogeneity or sensitivity analyses to evaluate the robustness of the synthesised results. To enhance the methodological rigour of this narrative review and address potential sources of bias, the quality of all included studies was independently assessed by two authors (SM and GG) using the Mixed Methods Appraisal Tool (MMAT), version 2018. For each study, the two screening questions were first evaluated, followed by the five core criteria appropriate to the study design category. Each criterion was rated as 'Yes', 'No', or 'Can't tell'. Disagreements between authors were resolved through discussion and consensus. In accordance with MMAT guidance, no overall quality score was calculated; instead, the detailed ratings for each criterion are presented to allow readers to evaluate strengths and limitations

**Table 1.** Type of articles included

Number of articles included, <i>n</i> (%)	30 (100)
Cross-sectional	14 (46.7)
Retrospective observational	3 (10.0)
Prospective observational	4 (13.3)
Clinical trial <sup>1</sup>	9 (30.0)
Published in 2020	6 (20.0)
Published in 2021	8 (26.7)
Published in 2022	5 (16.7)
Published in 2023	5 (16.7)
Published in 2024	6 (20.0)
Conducted in America	6 (20.0) <sup>2</sup>
Conducted in Africa	1 (3.3)
Conducted in Europe	13 (43.3) <sup>2</sup>
Conducted in Asia	6 (20.0)
Conducted in Oceania	5 (16.7)

*Notes:*

1. Seven randomised controlled trials and two non-randomised.

2. The study by W. Karazi et al.<sup>(21)</sup> recruited patients from both Europe and America, and was counted in both subgroups.

transparently. The results of this appraisal are reported in Supplementary Table S1.

### Results

The search conducted across the three databases led to an initial number of 960 articles: 272 from PubMed, 478 from Web of Science, and 210 from Scopus. After applying the inclusion and exclusion criteria, 101 articles were selected. After removal of duplicates, the number decreased to 47. Out of these papers, ten articles were excluded for not aligning with the objective of the current project. Full-text reading of the remaining 37 articles led to the exclusion of those that did not address any aspect of diet, nutrition, or lifestyle, or that focused only on caregivers rather than patients. Eventually, 30 studies were selected for the purpose of the review, inclusive of two more articles manually identified from the reference lists of the other papers<sup>(5–7,10,11,21–45)</sup>. The article selection and screening process is detailed in Figure 1.

The total number of patients investigated in this literature review was 5055. Regarding the subjects for whom age data were available (90.9%), 94.8% were adults (aged  $\geq 18$  years) and 5.2% were paediatric patients. The female population represented 51.7% (2587 out of 5001 people with available data), and out of the 1906 patients with available ethnicity data 95.8% were Asian, 4% Caucasian, while African and Hispanic ethnicities represented 0.1%. Education level data were available for 45% of patients (2275/5055) and out of these 10.2% had a low level of education, limited to elementary school, 23% completed elementary school (middle school), 25.9% completed secondary school (equivalent to high school in some educational systems), and 38.3% completed higher school. Two patients (0.1%) reported having no formal education. Regarding employment status, data were available for 59.3% of the study population (2996/5055): 18.4% were unemployed, while 38.3% were currently employed (whether full-time or part-time was not specified), 31.3% had to quit work activities because of the

**Table 2.** Demographic data

Number of patients included, <i>n</i> (%)	5055 (100)
<b>Age</b>	
Patients with available data <sup>1</sup>	4596 (90.9)
Patients <18 years old	241 (5.2)
Patients ≥18 years old	4355 (94.8)
<b>Gender</b>	
Patients with available data	5001 (98.9)
Male	2414 (48.3)
Female	2587 (51.7)
<b>Ethnicity</b>	
Patients with available data	1906 (37.7)
Caucasians	76 (4.0)
Africans	2 (0.1)
Asians	1826 (95.8)
Hispanics	2 (0.1)
<b>Level of education</b>	
Patients with available data <sup>2</sup>	2275 (45.0)
Without education	2 (0.09)
Low education	233 (10.2)
Elementary school	524 (23.0)
Secondary school	589 (25.9)
University	872 (38.3)
<b>Employment</b>	
Patients with available data	2996 (59.3)
Unemployed	553 (18.4)
Employed (type of contract not indicated)	1149 (38.3)
Retired by illness	939 (31.3)
Retired by age	328 (10.9)
Students	27 (0.9)

**Notes:**

1. The total count included only those patients for whom age was expressed as a mean and standard deviation; the count excluded those items with median and classes/age groups.

2. Included 55 patients whose level of education was not specified and 12 children attending elementary school.

disease, 10.9% were retired, and 0.9% (a total of 27 patients) were students. All demographic data for the study population are summarised in Table 2.

Most patients were affected by myasthenia gravis (MG; *n* = 3371; 66.7%), followed by those with amyotrophic lateral sclerosis (ALS; *n* = 501; 9.9%), Duchenne muscular dystrophy (DMD; *n* = 327; 6.5%), and facioscapulohumeral dystrophy (FSHD; *n* = 212; 4.2%). In addition, patients with myopathies of different origins (3.4%), spinal muscular atrophy (SMA; 0.7%), oculopharyngeal muscular dystrophy (0.7%) and other muscular dystrophies (MD; 1.5%), Charcot-Marie-Tooth pathology (CMT; 0.5%), and Pompe disease (0.3%) were included. Patients with other rare neuromuscular conditions were grouped in the 'other' category, accounting for 5.7% of the whole study population.

Drug therapy data were available for 4050 patients and among them 40.3% (*n* = 1631) were on steroid treatment. Moreover,

15.1% of all patients (*n* = 763) reported data about supplementation; among them, 24.5% were supplemented with vitamins, of which 11.8% were with vitamin D, 9.6% with minerals, especially calcium (3.1%), and 15.3% with other types of supplements. No patients were on protein supplementation and 35.6% did not report supplements intake.

Data on type of nutrition were available for 1232 patients (22.4%), of whom 94.8% were fed orally, while 5.2% relied on artificial nutrition. Evaluation of gastrointestinal disorders was available for 2071 patients (41% of the sample); among them, 10.4% reported dysphagia or difficult swallowing. Other reported gastrointestinal complaints included diarrhoea (3.5%), constipation (3.0%), gastroesophageal reflux (2.5%), nausea (0.9%), and vomiting (0.4%).

No data related to microbiota were identified in any included studies.

Regarding comorbidities, data were collected for 3273 patients (64.7%). Among them, 19.1% suffered from hypertension, 16.3% from neuropsychiatric disorders, 13.7% from osteoporosis, and 7.6% from dyslipidaemia. Other less frequent comorbidities included type 2 diabetes (6.3%), respiratory disease (4.8%), cardiovascular disease (2.5%), and liver disease (0.8%). The least frequently reported comorbidities were grouped in the 'other' category (26.0%). In some studies, comorbidities were an exclusion criterion; these patients accounted for 16.1% of the total.

All clinical data for the 5055 patients included in this systematic review are summarised in Table 3.

### Anthropometric data and nutritional status

The anthropometric data collected are shown in Table 4. Most of the selected studies (22/30) assessed weight, height, and BMI: information was available for 2912 patients (57.6%), and among them 82.4% were described by mean and standard deviation or median and with z-score assessment. Regarding nutritional status, 513 patients (10.1%) were classified according to WHO criteria<sup>(46)</sup> as: underweight (13.2%), normal weight (48.0%), overweight (27.9%), and obese (10.9%). Waist circumference data were collected in the cross-sectional study by Amzali and collaborators<sup>(5)</sup> and in the clinical trial by Billich et al.<sup>(24)</sup>; data were available for 211 patients (4.2%), expressed as mean and standard deviation or median. In Nishizawa's observational study<sup>(37)</sup>, the circumference of the lower limb was assessed as an instrument to quantify muscle mass. In eight studies, data about body composition were available: five studies used bio-impedance<sup>(5,34,39,42,44)</sup> and three used dual-energy X-ray absorptiometry (DEXA) instruments<sup>(6,11,26)</sup>. Analyses of body composition, discriminating between fat mass and lean mass, involved a total of 307 patients (6.1%). Finally, malnutrition risk screening was conducted in four studies<sup>(10,11,34)</sup> for a total of 234 patients (4.6%), of whom 27.3% (*n* = 64) were found to be at risk of severe malnutrition. The most detailed results on malnutrition risk were obtained by Forgues and colleagues<sup>(10)</sup>, using the Seniors in the Community Risk Evaluation for Eating and Nutrition (SCREEN II) score, and by Lopez-Gomez<sup>(34)</sup>, using the Subjective Global Assessment (SGA) screening tool according to GLIM criteria.

In detail, Forgues et al.<sup>(10)</sup> found that 82% of patients with oculopharyngeal muscular dystrophy were at risk for malnutrition, often associated with dysphagia. Lopez-Gomez<sup>(34)</sup>, in his research on ALS patients, noted that nearly half of patients (48%) were screened for malnutrition and that those with worsened nutritional

**Table 3.** Clinical data

Number of patients included, <i>n</i> (%)	5055 (100)
<b>Neuromuscular disorder</b>	
Patients with available data	5055 (100)
Amyotrophic lateral sclerosis	501 (9.9)
Charcot-Marie-Tooth	27 (0.5)
Duchenne muscular dystrophy	327 (6.5)
Facioscapulohumeral dystrophy	212 (4.2)
Muscular dystrophy	74 (1.5)
Myasthenia gravis	3371 (66.7)
Myopathy	171 (3.4)
Oculopharyngeal muscular dystrophy	33 (0.7)
Pompe disease	15 (0.3)
Spinal muscular atrophy	34 (0.7)
Others	290 (5.7)
<b>Steroid treatment</b>	
Patients with available data regarding drug therapy	4050 (80.1)
Steroid therapy	1631 (40.3)
<b>Supplementation</b>	
Patients with available data	763 (15.1)
Vitamins	187 (24.5)
Vitamin D	90 (11.8)
Minerals	73 (9.6)
Calcium	24 (3.1)
Protein	0 (0)
Other	117 (15.3)
None	272 (35.6)
<b>Type of nutrition</b>	
Patients with available data	1232 (22.4)
Oral nutrition	1173 (94.8)
Artificial nutrition	59 (5.2)
<b>Gastrointestinal disorders</b>	
Patients with available data	2071 (41.0)
Constipation	63 (3.0)
Diarrhoea	72 (3.5)
Dysphagia or swallowing problems	216 (10.4)
Gastroesophageal reflux	52 (2.5)
Nausea	19 (0.9)
Vomiting	8 (0.4)
<b>Microbiota analysis</b>	
Patients with available data	0 (0)
<b>Comorbidities</b>	
Patients with available data	3273 (64.8)
Cardiovascular disease	83 (2.5)

(Continued)

**Table 3.** (Continued)

Number of patients included, <i>n</i> (%)	5055 (100)
Dyslipidaemia	248 (7.6)
Hypertension	626 (19.1)
Hepatic involvement	26 (0.8)
Neuropsychiatric disorders	535 (16.3)
Osteoporosis	449 (13.7)
Respiratory diseases	157 (4.8)
Type 2 diabetes	207 (6.3)
Other	851 (26.0)
None	526 (16.1)

status had a lower life expectancy than those in optimal nutritional condition.

In such heterogeneous and progressive diseases, nutritional status changes greatly, and in observational studies performed by Naume and by Chou<sup>(7,11)</sup>, more than 50% of patients had inadequate body weight, ranging from overweight and obesity in Duchenne muscular dystrophy in paediatric patients, to underweight in other conditions such as motor neuron disease, muscular spinal atrophy, and myotonic dystrophy type 1.

Table 5 details data about diet and nutrition and all the other available lifestyle factors, if addressed (physical activity, smoking and/or alcohol dependence, sleep quality, psychological and emotional conditions, and patients' perceptions). Seven studies (23.3%) examined three or more aspects of lifestyle, eight studies (26.7%) focused on two aspects, and 15 articles (50.0%) examined a single aspect of lifestyle. None provided a comprehensive analysis of all relevant lifestyle factors in these conditions.

The summary of key information extracted from selected articles, such as the type of study, country, sample size, and all aspects of lifestyle investigated, is reported in Table 6. The evaluation of the methodological quality of the selected studies is reported in Supplementary Table S1.

A descriptive analysis of diet and nutrition and of any other addressed lifestyle factors (including physical activity, sleep quality, smoking and alcohol consumption habits, and emotional perception and care) was performed.

### Diet and nutrition

Diet and/or nutrition were investigated in 21 studies (12 observational and 9 clinical trials), with data from 1299 patients (25.7% of the selected total sample). In five intervention studies<sup>(29,31,35,39,40)</sup> the authors investigated the effect of special dietary patterns on patients' symptoms and/or life expectancy. Specifically, in the work of Dorst et al. and Ludolph et al.<sup>(29,35)</sup>, the effect of a high-calorie diet was evaluated in comparison to a control group without supplementation, while in the study of Gazzellone et al.<sup>(31)</sup> the 'Mad Dog Diet', an anti-inflammatory diet programme, was tested. In the study of Sechi et al.<sup>(39)</sup>, the effect of a high-protein diet combined with exercise was compared to the exercise programme alone, without any nutritional intervention. The work conducted by the Staretz-Chacham<sup>(40)</sup> research group evaluated the effect of a restrictive ketogenic diet on a small group of patients. Specific supplementations evaluated in patients with DMD or FSHD were

**Table 4.** Anthropometric data and nutritional status

BMI (kg/m <sup>2</sup> ) or z-score included, n (%)	
Patients with available data	2912 (57.6)
Data expressed as mean, standard deviation or median	2399 (82.4)
Data of BMI category	513 (17.6)
Underweight	68 (13.2)
Normal weight	246 (48.0)
Overweight	143 (27.9)
Obese (>30)	56 (10.9)
Waist circumference	
Patients with available data	211 (4.2)
Mean, standard deviation or median	211 (100)
Body composition (fat mass – lean mass)	
Patients with available data	307 (6.1)
Screening for malnutrition	
Patients with available data	234 (4.6)
At risk for severe malnutrition	64 (27.3)

**Table 5.** Lifestyle aspects

Lifestyle aspects included, n (%)	
All aspects analysed	0 (0.0)
Three or more aspects analysed	7 (23.3)
Two aspects analysed	8 (26.7)
One aspect analysed	15 (50.0)
Diet/food habits	21 (70)
Physical activity	16 (53.3)
Sleep quality	2 (6.7)
Addictions (smoking and/or alcohol)	2 (6.7)
Emotional perception and care	11 (36.7)
Diet/eating habits	
Patients with available data	1299 (25.7)
Physical activity	
Patients with available data	4220 (83.5)
Sleep quality	
Patients with available data	807 (16.0)
Addictions	
Patients with available data	189 (3.7)
Current smokers	17(4.2)
Current drinkers	24 (6.0)
Emotional perception and care	
Patients with available data n (%)	3219 (63.7)

effective in improving motor performance, and in the second group of patients, at a statistically significant threshold<sup>(26,44)</sup>. The family-centred intensive lifestyle and weight management programme specifically studied for DMD patients by Billich and

collaborators<sup>(24)</sup> has been very successful both in terms of patients' satisfaction and QoL.

None of the selected studies considered adherence to the Mediterranean diet or proposed an intervention based on a Mediterranean dietary pattern. Only the Mad Dog Diet proposed by Gazzellone's group<sup>(31)</sup> shares common elements with the Mediterranean diet, such as the use of plant-based foods rich in antioxidants, fibre, and omega-3, and a reduced intake of refined and ultra-processed foods. However, this is not an intervention based on the Mediterranean diet.

Dietary intakes, expressed as energy and macro- and micro-nutrient composition, collected through food diaries, food frequencies questionnaires, or interviews, were evaluated in 13 observational studies<sup>(5,6,10,11,23,24,27,33,34,41,42,45)</sup>. Dietvost<sup>(27)</sup> found that intake of fibre, nuts, and dairy products, as well as liquids, was significantly lower than in a healthy population and below the recommended thresholds; these data were confirmed, especially with regard to protein and fibre, by van Hees and collaborators<sup>(42)</sup>. Billich and Yamamoto<sup>(24,45)</sup> evaluated patients' refusal or avoidance behaviour with respect to certain foods or textures, and Chou<sup>(7)</sup> investigated how many of the recruited subjects had received dietary advice from a nutrition specialist. Finally, Billich<sup>(25)</sup> reported that, according to caregivers, patients experienced an increased appetite and often ate discretionary foods.

In clinical trials based on targeted dietary interventions, in which caloric and macro- and micronutrient intakes were optimised, an improvement of motor skills, expressed as increased fatigue tolerance, was observed in different pathologic conditions. In the presence of overweight and/or obesity, an improvement in BMI was observed, as well as a reduction of waist circumference<sup>(24,26,29,31,35,39,44)</sup>. Specific dietary intervention, such as a high-protein diet or a ketogenic diet, was found to be effective in improving some metabolic parameters and motor functions<sup>(39–41)</sup>. However, none of the clinical trials examined observed a significantly positive correlation between dietary intervention and survival. The study by Gazzellone and co-workers, a randomised controlled trial performed with 11 patients with different pathologic conditions, found a significant correlation between an anti-inflammatory diet, based on the consumption of fresh and minimally processed food, and improvement in depression<sup>(31)</sup>.

Overall, observational studies revealed that macro- and micronutrient intakes were frequently far from international recommended levels<sup>(30,47)</sup>, especially for protein<sup>(5,6,10,11,30,33,34)</sup> and lipid intakes<sup>(5,33,34)</sup>. Vitamin C, zinc, calcium, and vitamin E were frequently insufficient too<sup>(5,6,26)</sup>. Reduced consumption of fresh fruit and vegetables emerged in several studies<sup>(5,6,10,30)</sup> and, as a consequence, levels of dietary fibre were often found to be far below optimal intake levels<sup>(7,10,27,30)</sup>. Moreover, the analysis of diet quality revealed that many patients consumed foods high in calories, but low in nutrients, and that at least 30% of calories were derived from discretionary foods and drinks<sup>(6)</sup>.

In ten studies, the use of supplements was reported: four were clinical trials as part of the intervention<sup>(24,26,40,44)</sup>, while in the other contexts both commercial multivitamins and targeted supplements, such as vitamin D, calcium, and omega-3, were independently consumed<sup>(6,10,11,33,41)</sup>.

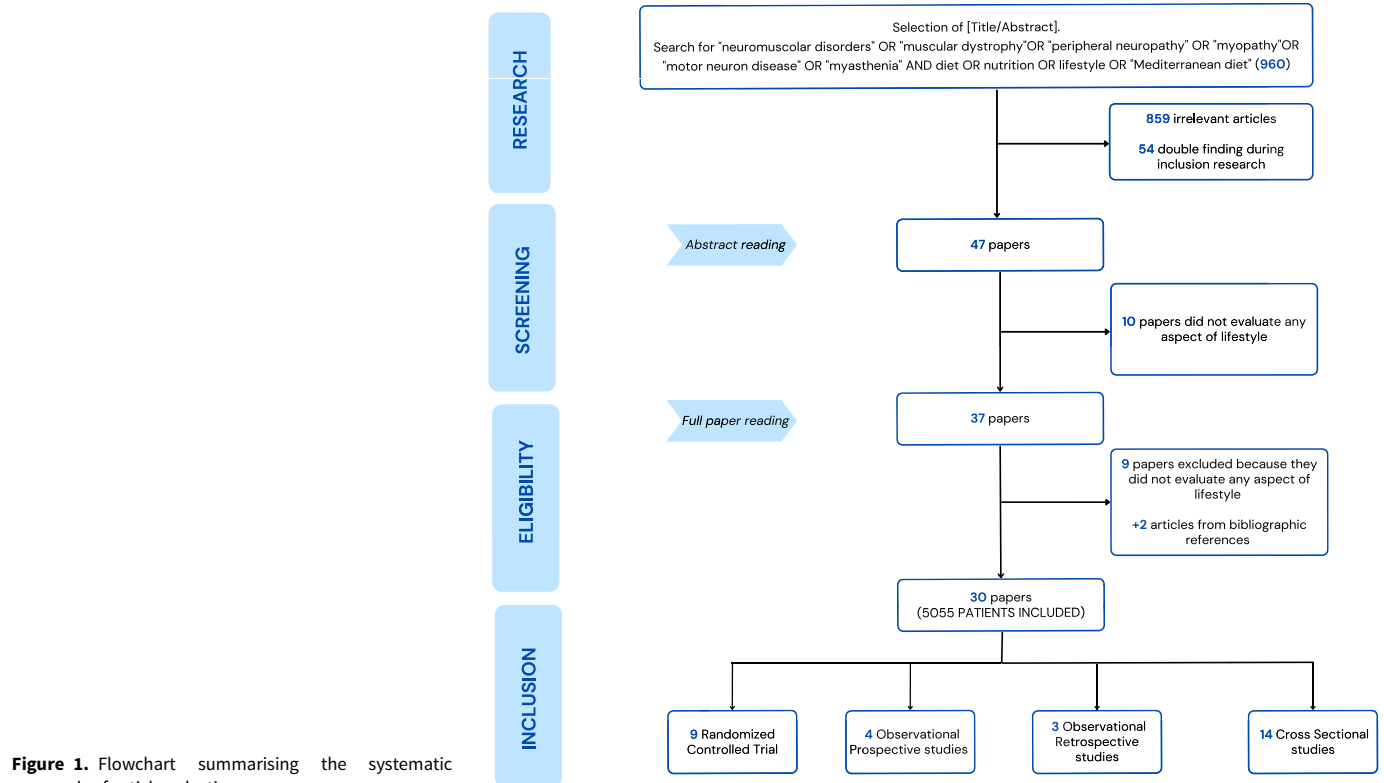
In the intervention study conducted by Wilson and colleagues, a supplementation of vitamin C, vitamin E, zinc, and selenium significantly improved muscle volume and function in patients with FSHD<sup>(44)</sup>.

Finally, nutrition education interventions, in which both patients and caregivers or targeting groups were involved, were

**Table 6.** List of selected studies with first author, year of publication, country, type of study, number of patients, and investigated aspects of lifestyle

First author	Year of publication	Country	Type of study	Number of patients	Diet and nutrition	Physical activity	Emotional status	Sleep quality	Addictions
Amzali, S <sup>(5)</sup>	2023	France	CS	159	✓	✓	-	-	-
Andersen, LK <sup>(22)</sup>	2021	Denmark	CS	779	-	✓	✓	✓	-
Andersen, LK <sup>(23)</sup>	2022	Denmark	CS	691	-	✓	-	-	-
Billich, N <sup>(24)</sup>	2024	Australia	CT	8	✓	✓	✓	-	-
Billich, N <sup>(25)</sup>	2024	Australia	CS	59	✓	✓	✓	-	-
Billich, N <sup>(6)</sup>	2022	Australia	CS	37	✓	✓	-	-	-
Chou, E <sup>(7)</sup>	2021	Australia	CS	160	✓	-	-	-	-
Davidson, ZE <sup>(26)</sup>	2021	Australia	RCT	36	✓	✓	-	-	-
Dietvorst, C <sup>(27)</sup>	2022	Netherlands	CS	48	✓	-	-	-	-
Dong, D <sup>(28)</sup>	2020	China	CS	1815	-	✓	✓	-	-
Dorst, J <sup>(29)</sup>	2022	Germany	RCT	64	✓	-	-	-	-
Elkady, AFH <sup>(30)</sup>	2023	Egypt	CS	57	✓	✓	✓	-	-
Forgues, C <sup>(9)</sup>	2021	Canada	CS	33	✓	-	-	-	-
Gazzellone, G <sup>(31)</sup>	2023	Canada	RCT	11	✓	-	✓	-	-
Jackson, K <sup>(32)</sup>	2023	USA	CS	28	-	✓	✓	✓	-
Karazi, W <sup>(21)</sup>	2024	Netherlands, Denmark, France, Spain, Germany, USA	CS	130	-	✓	-	-	-
Kim, B <sup>(33)</sup>	2020	South Korea	OP	148	✓	✓	-	-	✓
Lopez-Gomez, JJ <sup>(34)</sup>	2020	Spain	OP	93	✓	-	-	-	-
Ludolph, AC <sup>(35)</sup>	2020	Germany	RCT	201	✓	-	✓	-	-
McMillan, RA <sup>(36)</sup>	2021	USA	OR	41	-	-	-	-	✓
Naume, MM <sup>(10)</sup>	2022	Denmark	OP	44	✓	-	-	-	-
Nishizawa, H <sup>(37)</sup>	2021	Japan	OR	12	-	✓	-	-	-
Said, MA <sup>(38)</sup>	2024	Saudi Arabia	CS	238	-	✓	✓	-	-
Sechi, A <sup>(39)</sup>	2020	Italy	RCT	13	✓	✓	✓	-	-
Staretz-Chacham, O <sup>(40)</sup>	2021	Israel	RCT	12	✓	-	-	-	-
Ucar, SK <sup>(41)</sup>	2024	Turkey	OP	10	✓	✓	-	-	-
Van Hees, SMG <sup>(42)</sup>	2020	Netherlands	CT	9	✓	-	-	-	-
Walker, M <sup>(43)</sup>	2021	Canada	CS	10	-	-	✓	-	-
Wilson, VD <sup>(44)</sup>	2024	France	RCT	53	✓	-	-	-	-
Yamamoto, T <sup>(45)</sup>	2023	Japan	OR	56	✓	-	-	-	-

Note: CS, cross-sectional; OR, observational retrospective; OP, observational prospective; RCT, randomised clinical trial; CT, clinical trial.



**Figure 1.** Flowchart summarising the systematic approach of article selection.

found to be effective in improving eating habits and the management of daily meals<sup>(25,42)</sup>.

### Other lifestyle factors

In addition to diet and nutrition, all other lifestyle factors that emerged in this literature review were analysed.

Physical activity (PA) was analysed in 16 studies (53.3%), including 3 clinical trials and 13 observational studies, and involving a total of 4220 patients out of 5055 (83.5%) (Table 5).

The studies by Amzali et al.<sup>(5)</sup>, Andersen et al.<sup>(23)</sup>, Billich et al.<sup>(6)</sup>, Davidson et al.<sup>(26)</sup>, Dong et al.<sup>(28)</sup>, Elkady et al.<sup>(30)</sup>, Jackson et al.<sup>(32)</sup>, Karazi et al.<sup>(21)</sup>, Kim et al.<sup>(33)</sup>, Nishizawa et al.<sup>(37)</sup>, Said et al.<sup>(38)</sup>, and Ucar et al.<sup>(41)</sup> collected data on participants' actual physical activity and/or motor function, using assessment tools and scales not always comparable.

Assessment of PA has been conducted through questionnaires, interviews, and/or rating scales in 13 studies; more specific instruments, such as accelerometers<sup>(23)</sup>, tests conducted with health professionals<sup>(6,39)</sup>, and the '6-Minute Walk Distance (6MWD)<sup>(24,26,41)</sup> were used in six papers.

Three intervention studies<sup>(24,26,39)</sup> examined motor function and physical activity in patients with neuromuscular diseases. The pilot study by Billich et al. showed a trend toward improved motor function and fatigue tolerance, although not statistically significant, after a lifestyle and weight management programme<sup>(24)</sup>.

In the work of Davidson et al., a significant increase in 6MWD test performance and an improvement of daily activity parameters were observed after the use of an enhanced supplement. Body composition and quality of life of these DMD patients did not change<sup>(26)</sup>. Sechi's group observed that an exercise programme combined with a high-protein diet improved aerobic function, lung capacity, and QoL in late-onset Pompe disease patients. In

this intervention study, a personalised exercise training programme, combined with a high-protein diet, could significantly improve maximal muscular performance, exercise tolerance, vitality, and general health in comparison to the control group<sup>(39)</sup>.

Data from observational studies showed that, even taking into account different disease conditions, the physical activity level of most patients with neuromuscular diseases was overall lower than the minimum level of WHO recommendations<sup>(48)</sup>. In addition, this tendency toward a reduced physical activity was more pronounced among females than males<sup>(22,23,28,38)</sup>. The extensive observational study performed by Dong and co-workers found that women with MG had a significantly worse physical quality of life and a lower level of active lifestyle in comparison to men with the same clinical condition ( $p < 0.001$  and  $p < 0.01$ , respectively)<sup>(28)</sup>. Andersen et al. observed that 53% of patients with MG had a low level of PA, especially among females. Authors found a significant correlation between poor PA and higher BMI, older age, presence of comorbidities, reduced QoL, sleep disorders, and increased levels of fatigue<sup>(22)</sup>. In a subsequent study by Andersen and collaborators, conducted by accelerometer and IPAQ test, it was observed that 48% of patients with MG did not meet the moderate intensity recommendations<sup>(23)</sup>. Jackson et al. observed that participation in sports was challenging for patients with MG, and symptoms often induced withdrawal of PA<sup>(32)</sup>. In the work of Amzali, 84% of patients with FHSD reported low level of PA, and in women it was significantly lower than in men. Simultaneously, PA was positively related to younger age, daily energy intake, and zinc blood level<sup>(5)</sup>. The study of Billich et al.<sup>(6)</sup> reported a weak positive correlation between motor performance and energy intake ( $p < 0.01$ ) and Nishizawa and collaborators observed that a more sedentary lifestyle and lack of PA significantly decreased motor performance of patients with DMD<sup>(21,37)</sup>. In the observational transversal study of Karazi, 47% of the patients with myopathy did not perform

vigorous PA, 29% of the patients did not perform moderate PA, and 13% did not walk for at least ten minutes a day<sup>(21,33)</sup>, while in the study of Kim on ALS patients, 61% of subjects were reported to do exercise more than once a week<sup>(33)</sup>.

In the prospective study by Ucar et al.<sup>(41)</sup>, it was observed that a diet high in protein and fat led to increased exercise tolerance and motor function in paediatric patients with glycogen storage disease. Moreover, the daily activity questionnaire scores significantly improved in comparison to the initial self-evaluation<sup>(41)</sup>. Finally, Said and collaborators observed that more than 60% of patients, especially men, with different disabilities involved in the observational study, met the minimum standard of PA specified by WHO. Authors also observed that PA was significantly related to education level, type of disability (poliomyelitis exhibited the highest level of PA), and self-rated health<sup>(38)</sup>.

With regard to other lifestyle factors that emerged from this review, sleep quality was assessed in two observational studies, both conducted on patients suffering from MG<sup>(22,32)</sup>. Self-reported sleep quality and sleep disturbance during the previous two weeks were measured by Andersen and colleagues using the Insomnia Severity Index, with 55% of patients reporting insomnia. In addition, significantly more sleep problems were reported in the group of patients with lower physical activity. Insomnia also correlated with general fatigue, reduced activity and motivation, and mental fatigue<sup>(22)</sup>.

Jackson and co-workers conducted structured interviews, and the common symptoms identified by patients revealed that the main sleep problems were caused by respiratory problems or preoccupation with illness<sup>(32)</sup>.

Alcohol consumption and tobacco use were investigated in two articles<sup>(33,36)</sup>: in the papers by Kim et al. and by McMillan et al., alcohol consumption and smoking status were obtained by interviews and reported in the results as 'current', 'former', or 'never' drinking or smoking. Notably, in both studies, authors did not look for any correlation between tobacco use or alcohol consumption and pathological condition, QoL, or survival<sup>(33,36)</sup>.

No data on abuse of substances were identified in the articles selected in this systematic review.

The emotional and psychological status of patients was investigated in 11 studies (36.7%), 4 clinical trials<sup>(24,31,35,39)</sup> and 7 observational studies<sup>(22,25,28,30,32,38,43)</sup>, with data available for 3219 of 5055 patients (63.7%). The most frequently investigated emotional aspects involved conditions of anxiety and depression, which were examined in the work of Andersen et al., Billich et al., Dong et al., Gazzellone et al., Jackson et al., and Ludolph et al.<sup>(22,24,28,31,32,35)</sup>. Other studies explored the relationship between emotions and eating behaviours or focused attention on stress management, emotional well-being, and vitality of patients<sup>(25,30,39)</sup>. Among clinical trials, of note was the work of Gazzellone and collaborators, where an anti-inflammatory diet succeeded in significantly improving depression status measured by the Centre for Epidemiological Studies Depression Scale (CES-D)<sup>(31)</sup>. Sechi et al. also observed a trend in improvement in emotional state following a combined diet and physical activity intervention, although none of these studies reached statistical significance, probably due to a small sample size<sup>(39)</sup>. In the study of Ludolph, 3% of the sample reported depression, and the dietary intervention did not significantly change their perceived QoL<sup>(35)</sup>. Finally, in Billich's well-being intervention trial, the impact on anxiety, reported at baseline in three out of eight DMD patients, was not evaluated<sup>(24)</sup>.

Data on emotional condition and perception, collected in the different observational studies mainly at baseline, vary greatly,

even in similar pathological conditions. In the article of Andersen, 8% of patients with MG reported depression or anxiety, and this condition significantly correlated with fatigue (general, physical, and mental) and reduced activity and motivation<sup>(22)</sup>. In the large observational study performed by Dong and co-workers on Chinese patients with MG, depression was reported by 10.1% of men and 10.6% of women, and anxiety by 12.7% of men and 12.5% of women. Authors observed that MG also affected the emotional status in the female population more than in males<sup>(28)</sup>.

In the study by Jackson et al.<sup>(32)</sup>, conducted in patients with MS, anxiety and depression affected 82% and 75% of the population, respectively. Moreover, frustration (64% of patients), stress (32%), and discomfort (18%) were reported, and patients referred to difficulties in interpersonal relationships, a sense of misunderstanding by friends and family, anxiety related to social occasions, and a tendency to avoid relational events. Reduced sociality and difficulties in managing relationships both within and outside the family emerge as factors that severely affect the QoL perceived<sup>(32)</sup>. Elkady recorded, with the health promotion behaviour scale test, an intermediate level of stress management and self-actualisation among MG patients<sup>(30,38)</sup>.

In the study by Said and collaborators, where patients with different NMDs were enrolled, health perception was significantly better in those who were physically active ( $p < 0.001$ )<sup>(38)</sup>.

In projects involving both patients and caregivers in small groups, it was also possible to investigate correlations between pathology, emotions, and eating habits: sadness, depression, anger, boredom, and pleasure were associated with food consumption in 14% of patients with DMD<sup>(25)</sup>. In the qualitative study of Walker, through semi-structured interviews on weight management, the psychosocial well-being of boys with DMD and families was discussed, and the importance of an integrated and multidisciplinary approach was highlighted. A higher level of engagement among mothers also emerged<sup>(43)</sup>.

### Primary and secondary endpoints

Among the 30 studies evaluated in this narrative review, 11 enrolled paediatric patients (< 18 years; 36.7%)<sup>(6,7,10,24–27,37,40,41,43)</sup>, 9 enrolled young to middle-aged adults (age 18–50 years; 30%)<sup>(5,28,30,32,38,39,42,44,45)</sup>, and 10 enrolled adults (mean age >50 years; 33.3%)<sup>(9,21–23,29,31,33–36)</sup>. This age distribution reflects the natural course of these heterogeneous conditions: genetic dystrophies (DMD, SMA) typically manifest during childhood; myopathies and limb-girdle muscular dystrophies tend to manifest in early adulthood; MG, ALS, and inclusion body myositis are predominantly diseases that affect middle-aged and elderly adults.

In this narrative review, we also search for possible correlations of lifestyle on disease course (19 studies) and on QoL (nine studies, four as primary and five as secondary endpoint).

As for changes in pathology-related parameters, the studies vary greatly according to different diseases: in patients with ALS, a higher body weight was positively correlated with a prolonged survival rate, and an increased intake of protein, fats, and meat was positively associated both with long-term survival and symptoms delay<sup>(33)</sup>. A fat-rich diet, even if effective in improving weight gain, caused gastrointestinal side effects in several ALS patients<sup>(29)</sup>. In the intervention study of Ludolph and collaborators, a high-caloric nutrition programme did not increase the survival time, nor the vital capacity and functionality of ALS patients<sup>(35)</sup>.

In MG patients, higher physical activity seems to improve symptoms and fatigue resistance and, globally, these patients

registered a better health condition and quality of life<sup>(22,23)</sup>. One third of the MS patients involved in the observational study of Elkady achieved a low level of healthy promotion behaviours, including reduced physical activity<sup>(21,30)</sup>. Lower physical activity was related to worst parameters and, overall, to a poorer quality of life, also in patients with McArdle disease<sup>(21)</sup>. Physical activity is one of the aspects of the lifestyle that also affects the disease parameters in patients with DMD. Nishizawa and colleagues observed a significant reduction of motor function in patients with DMD in relation to the movements and travel restriction imposed during Covid-19 pandemic<sup>(37)</sup>.

Improved functional outcomes and ambulation in patients with DMD were achieved by antioxidant supplementation and higher protein intake<sup>(5,26)</sup>. Personalised dietary interventions, associated with lifestyle for weight management, have been reported by both DMD patients and caregivers to improve physical function and satisfaction<sup>(6,24,25)</sup>. Multidisciplinary interventions, involving both patients and caregivers, created a healthier environment and improved clinical outcomes<sup>(38,42,43)</sup>. In studies of different types of patients with neuromuscular diseases, it has been observed that a personalised dietary intervention and a multidisciplinary approach over time can improve health condition, including improving depression or mobility<sup>(31,41)</sup>.

Quality of life was measured through validated and standardised questionnaires, which allowed the assessment of various aspects, including physical, psychological, and emotional well-being: PedsQL, tailored for the paediatric population, was used by Billich<sup>(24)</sup> and Davidson<sup>(26)</sup>; for the adult population affected by MG, the specific MGQoL-15 was used by Andersen and by Dong<sup>(22,28)</sup>, and the SF-36 questionnaire, able to assess eight different areas of daily life, was used by Sechi and Wilson<sup>(39,44)</sup>. Due to the different and not comparable assessment methodologies, a comprehensive statistical analysis was not permitted. Improved QoL was observed in some intervention studies: Sechi et al. highlighted that individualised exercise programmes, in combination with tailored nutrition, have led to significant improvements not only in physical function but also in quality of life, particularly with regard to general health ( $p = 0.031$ ) and vitality ( $p = 0.031$ )<sup>(39,44)</sup>. Wilson and colleagues observed that antioxidant supplementation, with vitamin C, vitamin E, zinc, and selenium for 17 weeks, significantly improved the QoL of FSHD patients in terms of physical functioning, general health, vitality, emotional role functioning, and mental score. In the clinical trial of Staretz-Chacham, although not significant, a general trend of an increased QoL was observed in the ketogenic diet group<sup>(40)</sup>, while in the work of Davidson and Ludolph, performed on patients affected by DMD and ALS respectively, no meaningful improvements in QoL score were detected<sup>(26,35)</sup>. Observational studies have provided different results regarding QoL: Dong et al. identified that risk factors that could worsen QoL included female sex ( $p < 0.05$ ), a high number of comorbidities ( $p < 0.05$ ), and unemployment ( $p < 0.001$ ), while an active lifestyle had a positive impact on HRQoL ( $p < 0.001$ )<sup>(28)</sup>. In the study of Andersen (2021) the MGQoL-15 score was significantly higher in patients regularly involved in PA ( $p < 0.01$ )<sup>(22)</sup>, a trend also observed in patients with low motor capacity<sup>(24,33)</sup>. The importance of physical activity as a component of lifestyle has also emerged in the work of Elkady et al. and Ucar et al.<sup>(41)</sup>, who explored the effect of a high-protein diet and physical activity on increased motor capacity and QoL, with promising although not statistically significant results<sup>(30,41)</sup>. QoL is closely related also to the emotional state of patients: negative emotions, such as anxiety, depression, sadness, and frustration, have a direct impact on the

quality of social relationships, negatively affecting patients' overall well-being<sup>(25,39)</sup>. Impacts on social functioning, reported by the 96% of patients with MG enrolled in the study of Jackson, which included difficulties in dating, feeling misunderstood by friends and family, feeling uncomfortable/anxious in social situations, and skipping or avoiding social events, have been identified as significantly affecting the perceived QoL<sup>(32)</sup>.

### Disease-stratified endpoints

In the present narrative review, the findings on diet, physical activity, and QoL could also be presented separately for the three most represented disease groups (MG, ALS, DMD), which together account for 83.1% of the total study population ( $n = 4,199$  of 5,055). In patients affected by MG, physical activity and lifestyle management emerged as the most clinically actionable parameters, with PA consistently associated with lower fatigue (MFI-20) and better QoL (MG-QoL15) across multiple observational studies<sup>(7,22,23,28)</sup>. In patients affected by ALS, nutritional status and caloric support were central, but randomised clinical trial evidence has not demonstrated survival benefit even with high-caloric fat-rich supplementation<sup>(29,33,35)</sup>. In DMD, the nutritional picture is dominated by corticosteroid-driven weight gain, low fibre intake, and vitamin D deficiency, with interventional data suggesting a trend toward functional benefit from multicomponent supplementation<sup>(6,10,26,27)</sup>.

### Discussion

Patients with neuromuscular disorders frequently experience nutritional imbalances, from undernutrition and muscle atrophy to overweight and obesity, often exacerbated by disease progression<sup>(8,49,50)</sup>.

While pharmacological treatments are essential for symptom management, and in some settings are changing the course of pathology (i.e., spinal muscular atrophy)<sup>(51)</sup>, the role of various lifestyle factors, in particular nutrition and dietary habits, remains underexplored. Despite growing evidence on the impact of an unhealthy lifestyle on chronic diseases, such as cardiovascular and metabolic conditions and cancer, its influence on the clinical course and QoL of NMD patients has not been systematically evaluated.

In the present qualitative systematic review, for the first time, we addressed diet, nutrition, and Mediterranean diet as lifestyle factors affecting the clinical course and QoL of different NMD conditions. The heterogeneity in the clinical conditions and in the measurement methods of lifestyle aspects do not allow a quantitative analysis, but, overall, better management of diet and lifestyle and a higher level of health-promoting behaviours promoted symptom stability and improved general health, vitality, and QoL<sup>(22,24,25,32,33,39)</sup>.

Among NMD patients, anthropometric dynamics and nutritional status exhibit great differences according to the pathological conditions and their progression<sup>(1,7)</sup>. Although this population is at elevated risk for malnutrition, either by excess or deficiency, only 10% of the patients underwent nutritional screening, and, among them, less than 50% exhibited a normal weight according to WHO criteria<sup>(46)</sup>. This result highlights a critical gap in clinical practice, as timely nutritional assessment could facilitate early interventions to optimise dietary intake and prevent complications. Malnutrition-specific screenings were performed in a small percentage of patients, of whom approximately one third were found

to be at risk for severe malnutrition. Moreover, both the collection of waist circumference data, and even arm or calf circumference detection – quick and non-invasive methods to assess metabolic risk-related overweight and obesity, and malnutrition and muscle loss, respectively – were performed in a negligible proportion of subjects<sup>(5,24,37)</sup>. These data emphasise how anthropometric and malnutrition risk assessments are still poorly investigated, despite the well-documented consequences on health status, hospitalisation duration, and overall QoL. International guidelines, such as the GLIM criteria for malnutrition diagnosis, advocate for a more comprehensive assessment of nutritional risk, yet their implementation in NMDs remains limited<sup>(52)</sup>. Another aspect that is still underestimated is the assessment of body composition in terms of lean and fat mass. Dual-energy X-ray absorptiometry, widely used as a reference method in research, provides accurate measurements but is costly and not always accessible. Bioimpedance analysis, thanks to the technological improvements and increasing reliability of devices, represents a more practical and feasible approach for routine clinical settings, and may complement DEXA in the monitoring of patients with neuromuscular disorders<sup>(53)</sup>. The estimation of total body fat, the infiltration of fatty deposits between muscle fibres, and the amount of total muscle mass, are parameters that can monitor the progression of many NMDs and the effects of targeted interventions<sup>(5,34,39,44)</sup>; these rapid and very low-cost methods could be implemented.

Gastrointestinal conditions, such as gastroesophageal reflux disease, dysphagia, swallowing difficulties, constipation, and other impairments, heavily affect both the nutritional status and the QoL of NMD patients. After a timely assessment of the anthropometric measurements, the gastrointestinal function should also be evaluated as soon as possible, and, although no specific recommendations for all the NMDs are currently available, should be taken into account in the treatment pathway<sup>(8)</sup>. In the present systematic review, gastrointestinal function was assessed in about 40% of subjects, thus representing an additional aspect to be implemented.

Based on the above considerations, diet management and eating habits play a crucial role in the disease progression, symptoms improvement, and QoL in NMDs, and most of the articles included in the present review have investigated this aspect of lifestyle. Overall, observational studies detected both quantitative and qualitative deficiencies: calories, proteins, lipids, and fibres were often low in comparison to dietary recommendations, as well as vitamin C, vitamin E, zinc, selenium, and calcium. The analysis of diet quality showed a reduced consumption of fruit and vegetables, legumes, nuts, and seeds, substituted by discretionary foods. Clinical trials based on dietary interventions, mainly aimed at improving energy and macro- and micronutrient intakes, were found to be overall quite effective in improving motor skills, fatigue tolerance, and quality of life, although they have not significantly increased life expectancy<sup>(24,26,29,31,35,39,44)</sup>. High caloric diets adopted in all conditions characterised by severe malnutrition, such as ALS, provided reasonable results, but, due to low sample sizes and a high rate of drop-out, no statistically significant benefits were identified<sup>(29,35,54)</sup>. Protein supplementation has shown benefits in improving muscle mass and strength, stimulating muscle protein synthesis and counteracting the anabolic resistance in a population of frail individuals, and even in such a heterogeneous population the tendency is in favour of high-protein diets<sup>(39,55)</sup>. However, none of the selected papers used a protein supplement. The ketogenic diet (KD), a dietary pattern effectively proposed in some neurological patients, mainly those suffering from drug-

resistant epilepsy<sup>(56)</sup>, has been used in small studies of patients with NMDs. The ability to protect neurons from free radical damage and reduce oxidative stress and neuroinflammatory responses made KD a potential therapeutic adjuvant also in NMDs<sup>(57)</sup>. The small number of patients following a KD in this systematic review only allows us to observe a trend toward improvement of exercise tolerance<sup>(41)</sup> and QoL<sup>(40)</sup>. One of the aspects explored in this narrative review was the potential role of the Mediterranean diet in the context of neuromuscular disorders. None of the studies identified assessed adherence to the Mediterranean diet or proposed interventions based on a Mediterranean dietary pattern. A study assessed the potential of a dietary intervention based on foods rich in antioxidants, plant-based foods, and omega-3 fatty acids, which involved reducing the intake of sugars and refined foods. Although this intervention shares some characteristics with the Mediterranean diet, it represents a different dietary approach<sup>(31)</sup>.

Diet quality is another aspect that should be carefully investigated in the context of NMDs: increasing scientific evidence correlates diets rich in ultra-processed foods with alterations at the gut–brain axis level and a possible neurotoxic effect<sup>(58,59)</sup>. In the context of improving dietary fat quality, the replacement of ultra-processed snacks with whole, nutrient-dense foods such as nuts or nut-based spreads, may offer additional metabolic and cardiovascular benefits. A recent systematic review with Bayesian meta-analysis demonstrated that hazelnut consumption significantly improves blood lipid profiles, particularly by reducing total and LDL cholesterol, without negatively affecting body weight. These findings support the potential role of nut consumption as part of a Mediterranean dietary pattern in patients with neuromuscular disorders<sup>(60)</sup>. A poor diet quality, characterised by great consumption of high caloric food, rich in sugars and fats and poor in vegetables, legumes, and whole grains, has been detected among young DMD patients, thus promoting an inappropriate nutritional status. Given the increasing evidence linking ultra-processed foods to neurotoxicity and gut–brain axis dysfunction, dietary patterns rich in minimally processed, nutrient-dense foods, such as the Mediterranean diet, may offer a protective effect in NMDs<sup>(27,42)</sup>. Moreover, abundance of fibre could also improve gut function and glycaemic control. A greater adherence to a healthy dietary pattern, rich in antioxidants, polyphenols, and fibre, represents a promising approach also in neuromuscular disorders where oxidative stress plays a predominant role<sup>(18,19)</sup>. The Mediterranean lifestyle is also integrated by regular practice of physical activity and muscle-strengthening activities, adequate rest, and socialisation during meals<sup>(17)</sup>. Exhaustive studies focused on the effects of Mediterranean diet and lifestyle on NMD progression and QoL are still lacking. This gap highlights a promising avenue for future research aimed at integrating nutritional and lifestyle strategies into NMD management.

In addition to diet quality interventions, the involvement of both caregivers and patients appears to be more effective in increasing adherence, participant satisfaction, and QoL<sup>(25,42)</sup>.

With regard to the other lifestyle-related aspects among those identified in this literature review, physical activity appears to be a cornerstone in health promotion even in patients with NMDs: despite the many barriers to exercise these subjects may face, an overall positive correlation between PA and improved motor function and QoL has been observed. More active patients reported significantly increased fatigue tolerance from daily activity, although different pathological settings and different methods of investigation did not allow a uniform result to be derived. Overall,

these findings underscore the importance of considering exercise as a key lifestyle factor that can positively influence the evolution of these complex and disabling diseases<sup>(16)</sup>.

Increasing evidence suggests that insomnia, sleep loss, or circadian sleep disturbance may act as neurobiological stressors which directly contribute to neuroinflammation by increasing pro-inflammatory cytokines and negatively influencing neural plasticity, causing neuron loss, neural death, and neural injury<sup>(61)</sup>. In patients suffering from NMDs, respiratory problems, movement limitations, and worry about illness affect the sleep quality and duration, with a further impairment of general fatigue, motivation, and mental well-being. However, this aspect has been evaluated only marginally in this review, given the small number of articles selected, as was the case with smoking habits and addictions, did not allow exhaustive conclusions to be reached on the matter.

Data on emotional perception and care are available for a considerable proportion of patients selected for this systematic review: a better quality of diet, including specific supplements, greater involvement in physical activity, and better sleep hygiene are all factors that, in different studies, have been related to better emotional condition and a lower risk of developing depression or anxiety. On the other hand, negative emotional status, like anxiety, depression, and stress, are common in these patients, heavily affecting their QoL. This trend emphasises how different aspects of lifestyle have a synergistic effect and how they should therefore be analysed altogether. Social occasions and interpersonal relationships are referred to as difficult situations to manage and indeed generate concern; however, multidisciplinary approaches, through the involvement of caregivers and patient groups, have improved patient perception and engagement.

This review underscores how, even in the most complex neuromuscular disease settings, taking charge of nutrition, diet quality, and some lifestyle factors such as physical movement and emotional conditions could support the patient both in the course of the pathology and especially regarding QoL. Moreover, the active involvement of caregivers in both healthy behaviour knowledge and tailored interventions could also improve the QoL of these families.

Our results should be considered in the light of some limitations. First, the research methodology was more oriented towards diet and nutrition and less specific with regard to other aspects of lifestyle, such as sleep, smoking, alcohol consumption, anxiety, or depression. Moreover, heterogeneities among the selected studies, including study design, methods and reporting, sample size, type of disease, and endpoints, allowed a qualitative systematic descriptive analysis, and highlight the gaps in this research area. The randomised controlled trials identified cover only four conditions (ALS<sup>(29,35)</sup>; DMD<sup>(26)</sup>; FSHD<sup>(44)</sup>; rare metabolic NMD<sup>(39,40)</sup>) and address different interventions (hypercaloric diets, multicomponent supplements, ketogenic diet, exercise combined with diet), making design-based subgrouping methodologically inappropriate. Our search was restricted to studies published in the last five years, which may have excluded relevant earlier evidence. Furthermore, a considerable proportion of the collected data is related to patients with myasthenia gravis, while no studies were found that met the inclusion criteria dedicated to patients with Guillain-Barré syndrome, despite it being a well-known neuromuscular disorder, and this may influence overall outcomes. Moreover, the majority of patients were of Asian ethnicity, limiting external validity and generalisability.

However, to our knowledge this is the first systematic review offering a more comprehensive view of the complex

interrelationship between diet, nutrition, Mediterranean diet, lifestyle, and pathological parameters and QoL in NMD patients. This review emphasises that the assessment of nutritional status, body composition, and gastrointestinal function are elements that should be systematically explored within clinical practice in order to develop nutritional interventions adapted to each patient.

Given the multiple benefits of the Mediterranean diet in several neurological conditions<sup>(62)</sup>, the role it plays in neuromuscular disorders remains largely unexplored, both in terms of adherence to the Mediterranean diet and the implementation of dietary interventions based on the Mediterranean model. Future research should aim to standardise dietary and lifestyle assessment tools, implement multidisciplinary interventions, and explore the long-term impact of lifestyle modifications on both disease progression and patient-reported outcomes.

## Conclusion

In conclusion, given the heterogeneity and disabling nature of these disorders, it is crucial to consider the interplay of diet and lifestyle according to multidisciplinary and personalised approaches in order to significantly improve health outcomes and quality of life for patients and their families. A comprehensive, multidisciplinary approach to diet and lifestyle, including regular nutritional screening, promotion of physical activity adapted to individual functional capacity, psychological support, and family/caregiver involvement, appears to be the most promising strategy for improving clinical outcomes and QoL in these patients. Future research should prioritise adequately powered intervention trials, standardised nutritional assessment protocols, and the study of Mediterranean diet adherence and its potential neuroprotective effects in NMDs.

**Supplementary material.** The supplementary material for this article can be found at <https://doi.org/10.1017/S0954422426100420>

**Acknowledgements.** The authors thank Dr. Daria Cattaneo for her contribution during the initial stages of the project.

**Authorship.** S.M., G.G., B.Z., and M.F. conceived the idea for the study, and developed the rationale and research questions. S.M. and G.G. wrote the first draft of the manuscript. B.Z., M.F., M.M., G.M., B.R., A.P., and M.C. provided critical review and feedback at each stage of the process. A.P., M.C., B.Z., and M.F. supervised the project. All authors critically revised the manuscript for intellectual content and agreed and approved the final manuscript. S.M. is the guarantor of the review.

**Financial support.** This research received no specific grant from any funding agency, commercial or not-for-profit sectors.

**Competing interests.** The authors declare none.

## References

1. Salera S, Menni F, Moggio M, Guez S, Sciacco M, Esposito S (2017) Nutritional challenges in Duchenne muscular dystrophy. *Nutrients* **9**, 594–604.
2. Jones K, Hawke F, Newman J, Miller JA, Burns J, Jakovljevic DG, *et al.* (2021) Interventions for promoting physical activity in people with neuromuscular disease. *Cochrane Database Syst Rev* **5**, 1–123.
3. Mary P, Servais L, Vialle R (2018) Neuromuscular diseases: diagnosis and management. *Orthop Traumatol Surg Res* **104**, 89–95.
4. Dangoulouff T, Boemer F, Servais L (2021). Newborn screening of neuromuscular diseases. *Neuromuscul Disord* **31**, 1070–1080.

5. Amzali S, Wilson VD, Bommart S, Picot M-C, Galas S, Mercier J, *et al.* (2023) Nutritional status of patients with facioscapulohumeral muscular dystrophy. *Nutrients* **15**, 1673–1710.
6. Billich N, Evans M, Truby H, Ryan MM, Kornberg AJ, Davidson ZE (2022) The association between dietary factors and body weight and composition in boys with Duchenne muscular dystrophy. *J Hum Nutr Diet* **35**, 804–815.
7. Chou E, Lindeback R, D'Silva AM, Sampaio H, Neville K, Farrar MA (2021) Growth and nutrition in pediatric neuromuscular disorders. *Clin Nutr* **40**, 4341–4348.
8. Dipasquale V, Morello R, Romano C (2023) Gastrointestinal and nutritional care in pediatric neuromuscular disorders. *World J Clin Pediatr* **12**, 197–204.
9. Forgues C, Fortin J, Gagnon C, Brisson JD, Mathieu J, Brais B, *et al.* (2021) Nutritional risk in oculopharyngeal muscular dystrophy: beyond dysphagia. *Can J Diet Pract Res* **82**, 95–97.
10. Naume MM, Jørgensen MH, Høi-Hansen CE, Born AP, Vissing J, Borgwardt L, *et al.* (2023) Metabolic assessment in children with neuromuscular disorders shows risk of liver enlargement, steatosis and fibrosis. *Acta Paediatr Int J Paediatr* **112**, 846–853.
11. Zhang H, Qi G, Wang K, Yang J, Shen Y, Yang X, *et al.* (2023) Oxidative stress: roles in skeletal muscle atrophy. *Biochem Pharmacol* **214**, 115664–115679.
12. Choi MH, Ow JR, Yang ND, Taneja R (2016) Oxidative stress-mediated skeletal muscle degeneration: molecules, mechanisms, and therapies. *Oxid Med Cell Longevity* **2016**, 1–13.
13. Zaman CF, Sultana J, Dey P, Dutta J, Mustarin S, Tamanna N, *et al.* (2022) A multidisciplinary approach and current perspective of nonalcoholic fatty liver disease: a systematic review. *Cureus* **14**, 29657–29669.
14. Zhang X, Devlin HM, Smith B, Imperatore G, Thomas W, Lobelo F, *et al.* (2017) Effect of lifestyle interventions on cardiovascular risk factors among adults without impaired glucose tolerance or diabetes: a systematic review and meta-analysis. *Plos One* **12**, 176436–176463.
15. Voet NBM, van der Kooij EL, van Engelen BGM, Lindeman E, van Engelen BG, Geurts AC (2019) Strength training and aerobic exercise training for muscle disease. *Cochrane Database Syst Rev* **12**, 1–128.
16. Bettio C, Banchelli F, Salsi V, Vicini R, Crisafulli O, Ruggiero L, *et al.* (2024) Physical activity practiced at a young age is associated with a less severe subsequent clinical presentation in facioscapulohumeral muscular dystrophy. *BMC Musculoskelet Disord* **25**, 25–35.
17. Serra-Majem L, Tomaino L, Dernini S, Berry EM, Lairon D, Ngo de la Cruz J, *et al.* (2020) Updating the mediterranean diet pyramid toward sustainability: focus on environmental concerns. *Int J Environ Res Public Health* **17**, 8758–8778.
18. Petrella C, Di Certo MG, Gabanella F, Barbato C, Ceci FM, Greco A, *et al.* (2021) Mediterranean diet, brain and muscle: olive polyphenols and resveratrol protection in neurodegenerative and neuromuscular disorders. *Curr Med Chem* **28**, 7595–7613.
19. Bakurhan H, Özkaya V, Pehlivan M (2023) Mediterranean diet is associated with better gastrointestinal health and quality of life, and less nutrient deficiency in children/ adolescents with disabilities. *Front Public Health* **11**, 1243513–1243527.
20. Page MJ, Mckenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD *et al.* (2020) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ (Clin Res Ed)* **372**, 1–9.
21. Karazi W, Coppers J, Maas D, Cup E, Bloemen B, Voet N, *et al.* (2024) Toward an understanding of GSD5 (McArdle disease): how do individuals learn to live with the metabolic defect in daily life. *J Neuromuscul Dis* **11**, 103–116.
22. Andersen LK, Aadahl M, Vissing J, Knak KL (2021) Fatigue, physical activity and associated factors in 779 patients with myasthenia gravis. *Neuromuscul Disord* **31**, 716–725.
23. Andersen LK, Aadahl M, Vissing J (2022) Habitual physical activity in patients with myasthenia gravis assessed by accelerometry and questionnaire. *J Neuromuscul Dis* **9**, 161–169.
24. Billich N, Bray P, Truby H, Evans M, Carroll K, de Valle K, *et al.* (2024) Pilot study of a virtual weight management program for Duchenne muscular dystrophy. *Muscle Nerve* **69**, 459–466.
25. Billich N, Bray P, Truby H, Evans M, Ryan MM, Carroll K, *et al.* (2024) Exploring caregivers' attitudes and beliefs about nutrition and weight management for young people with Duchenne muscular dystrophy. *Muscle Nerve* **69**, 448–458.
26. Davidson ZE, Hughes I, Ryan MM, Kornberg AJ, Cairns AG, Jones K, *et al.* (2021) Effect of a multicomponent nutritional supplement on functional outcomes for Duchenne muscular dystrophy: a randomized controlled trial. *Clin Nutr* **40**, 4702–4711.
27. Dietvorst CAW, Bot D, Van Der Holst M, Niks EH (2022) The relation between nutritional intake and body weight in 4-18 year old patients with DMD: what could possibly be done to prevent weight gain? *J Neuromuscul Dis* **9**, 701–711.
28. Dong D, Chong MKC, Wu Y, Kaminski H, Cutter G, Xu X, *et al.* (2020) Gender differences in quality of life among patients with myasthenia gravis in China. *Health Qual Life Outcomes* **18**, 296–309.
29. Dorst J, Doenz J, Kandler K, Dreyhaupt J, Tumani H, Witzel S, *et al.* (2022) Fat-rich versus carbohydrate-rich nutrition in ALS: a randomised controlled study. *J Neurol Neurosurg Psychiatry* **93**, 298–302.
30. Elkady A, Ahmed B, Abd El- Naby A (2023). Predictors to health promoting behaviors among patients with myasthenia gravis: health belief model approach. *J Popul Ther Clin Pharmacol* **30**, 417–429.
31. Gazzellone G, Lanteigne S, Gammage K, Fajardo VA, Ditor DS (2023) The effects of an anti-inflammatory dietary consultation on self-efficacy, adherence and selected health outcomes: a randomized control trial. *Am J Lifestyle Med* **0**, 1–11.
32. Jackson K, Parthan A, Lauher-Charest M, Broderick L, Law N, Barnett C (2023) Understanding the symptom burden and impact of myasthenia gravis from the patient's perspective: a qualitative study. *Neurol Ther* **12**, 107–128.
33. Kim B, Jin Y, Kim SH, Park Y (2020) Association between macronutrient intake and amyotrophic lateral sclerosis prognosis. *Nutr Neurosci* **23**, 8–15.
34. López-Gómez JJ, Ballesteros-Pomar MD, Torres-Torres B, De la Maza BP, Penacho-Lázaro MÁ, Palacio-Mures JM, *et al.* (2021) Malnutrition at diagnosis in amyotrophic lateral sclerosis (ALS) and its influence on survival: using GLIM criteria. *Clin Nutr* **40**, 237–244.
35. Ludolph AC, Dorst J, Dreyhaupt J, Weishaupt JH, Kassubek J, Weiland U, *et al.* (2020) Effect of high-caloric nutrition on survival in amyotrophic lateral sclerosis. *Ann Neurol* **87**, 206–216.
36. McMillan RA, Bowen AJ, Bayan SL, Kasperbauer JL, Ekbohm DC (2021) Cricopharyngeal myotomy in inclusion body myositis: comparison of endoscopic and transcervical approaches. *Laryngoscope* **131**, 2426–2431.
37. Nishizawa H, Nakamura A (2021) Changes in motor function in Duchenne muscular dystrophy patients after travel restrictions due to COVID-19. *Muscle Nerve* **64**, 357–361.
38. Said MA, Alhumaid MM (2024) Appraising the physical activity levels of Saudis with physical disabilities: effects of disability type, mobility assistive devices, and demographic factors. *Healthcare (Basel)* **12**, 937–949.
39. Sechi A, Zuccarelli L, Grassi B, Frangiamore R, De Amicis R, Marzorati M, *et al.* (2020) Exercise training alone or in combination with high-protein diet in patients with late onset Pompe disease: results of a cross over study. *Orphanet J Rare Dis* **15**, 143–154.
40. Staretz-Chacham O, Pode-Shakkeb B, Kristal E, Abraham SY, Porper K, Wormser O, *et al.* (2021) The effects of a ketogenic diet on patients with dihydrolipoamide dehydrogenase deficiency. *Nutrients* **13**, 3523–3534.
41. Uçar S, Altınok YA, Mansuroglu Y, Canda E, Yazıcı H, Çelik MY, *et al.* (2024) Long-term personalized high-protein, high-fat diet in pediatric patients with glycogen storage disease type IIIa: evaluation of myopathy, metabolic control, physical activity, growth, and dietary compliance. *J Inherit Metab Dis* **47**, 1001–1017.
42. van Hees SGM, Knuijt S, Dicke H, Groothuis JT, Raaphorst J, Satink T, Cup EHC (2020) Meet and eat, an interdisciplinary group intervention for patients with myotonic dystrophy about healthy nutrition, meal preparation, and consumption: a feasibility study. *Disabil Rehabil* **42**, 1561–1568.
43. Walker M, Mistry B, Amin R, McAdam L, Kalnins D, Lui T, *et al.* (2022) A qualitative exploration of the priorities and experiences of children with Duchenne muscular dystrophy, their parents, and healthcare professionals around weight management. *Disabil Rehabil* **44**, 8234–8242.

44. Wilson VD, Bommart S, Passerieux E, Picot MC, Mercier J, Laoudj-Chenivesse D, *et al.* (2024) Muscle strength, quantity and quality and muscle fat quantity and their association with oxidative stress in patients with facioscapulohumeral muscular dystrophy: effect of antioxidant supplementation. *Free Radic Biol Med* **219**, 112–126.
45. Yamamoto T, Mori-Yoshimura M, Oya Y, Komaki H, Takahashi Y (2023) Factors influencing the decision to introduce alternative nutrition in patients with Duchenne muscular dystrophy. *Muscle Nerve* **68**, 737–742.
46. World Health Organization (WHO). A healthy lifestyle - WHO recommendations. <https://www.who.int/news-room/fact-sheets/detail/healthy-diet> (accessed February 2025).
47. United States Department of Agriculture. Nutrient recommendations and databases. <https://www.nal.usda.gov> (accessed February 2025).
48. World Health Organization (WHO). WHO guidelines on physical activity and sedentary behaviour. <https://www.who.int/publications/i/item/9789240015128> (accessed February 2025).
49. Deenen JCW, Horlings CGC, Verschuuren JJGM, Verbeek AL, van Engelen BG (2015) The epidemiology of neuromuscular disorders: a comprehensive overview of the literature. *J Neuromuscul Dis* **2**, 73–85.
50. Wernio E, Wasilewska E, Czaja-Stolc S, Śledzińska K, Wierzba J, Szlagaty-Sidorkiewicz A, *et al.* (2024) Nutritional issues among children with Duchenne muscular dystrophy—incidence of deficiency and excess body mass. *Nutrients* **16**, 2143–2155.
51. Oskoui M, Day JW, Deconinck N, Mazzone ES, Nascimento A, Saito K, *et al.* (2023) Correction to: two-year efficacy and safety of risdiplam in patients with type 2 or non-ambulant type 3 spinal muscular atrophy (SMA). *J Neurol* **270**, 2547–2549.
52. Cederholm T, Jensen GL, Correia MITD, Gonzalez MC, Fukushima R, Higashiguchi T, *et al.* (2019) GLIM criteria for the diagnosis of malnutrition – a consensus report from the global clinical nutrition community. *Clin Nutr* **38**, 1–9.
53. Ellegard L, Aldenbratt A, Svensson MK, Lindberg C (2019) Body composition in patients with primary neuromuscular disease assessed by dual energy X-ray absorptiometry (DXA) and three different bioimpedance devices. *Clin Nutr ESPEN* **29**, 142–48.
54. Prado MB Jr, Pedro KM, Adiao KJB (2023) Efficacy, safety and tolerability of high caloric diet in amyotrophic lateral sclerosis patients: a systematic review and meta-analysis. *Rev Neurol (Paris)* **179**, 1008–1019.
55. Yoshimura Y, Matsumoto A, Inoue T, Okamura M, Kuzuya M (2025) Protein supplementation alone or combined with exercise for sarcopenia and physical frailty: a systematic review and meta-analysis of randomized controlled trials. *Arch Gerontol Geriatr* **131**, 105783.
56. Wickstrom R, Taraschenko O, Dilena R, Payne ET, Specchio N, Nabbout R, *et al.* (2022) International consensus recommendations for management of new onset refractory status epilepticus including febrile infection-related epilepsy syndrome: statements and supporting evidence. *Epilepsia* **63**, 2840–2864.
57. Tao Y, Leng SX, Zhang H (2022) Ketogenic diet: an effective treatment approach for neurodegenerative diseases. *Curr Neuropharmacol* **20**, 2303–2319.
58. Cai C, Song Z, Xu X, Yang X, Wei S, Chen F, *et al.* (2025) The neurotoxicity of acrylamide in ultra-processed foods: interventions of polysaccharides through the microbiota–gut–brain axis. *Food Funct* **16**, 10–23.
59. González Olmo BM, Butler MJ, Barrientos RM (2021) Evolution of the human diet and its impact on gut microbiota, immune responses, and brain health. *Nutrients* **13**, 196–213.
60. Perna S, Giacosa A, Bonitta G, Bologna C, Isu A, Guido D, *et al.* (2016) Effects of hazelnut consumption on blood lipids and body weight: a systematic review and bayesian meta-analysis. *Nutrients* **8**, 747–764.
61. Palagini L, Manni R, Aguglia E, Amore M, Brugnoli R, Girardi P, *et al.* (2020) Expert opinions and consensus recommendations for the evaluation and management of insomnia in clinical practice: joint statements of five Italian scientific societies. *Front Psychiatry* **11**, 558–570.
62. Zuliani G, Gianfredi V, Veronese N, Volpe M, Maggi S, Onder G, *et al.* (2026) Efficacy of mediterranean diet for the prevention of neurological diseases: a systematic review and meta-analysis featured in the Italian national guidelines “La Dieta Mediterranea”. *Nutrition* **142**, 112990.